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Distribution, Community Structure & Species Succession of Copepods from Cochin Backwaters

M MADHUPRATAP

National Institute of Oceanography, Dona Paula, Goa 403 004

Received 28 September 1978

Ecological aspects of copepods, the major group of zooplankton in Cochin backwaters, based on year round collections from its lower reaches are presented. Truly estuarine and estuarine and marine species form the bulk of the composition along with a couple of euryhaline marine species. Most of the marine species are only stragglers into the estuary. Variations in the abundance are compared with estuaries elsewhere. Based on the spatial and temporal abundance various species of copepoda fall into different groups which together dovetail to project their overall distribution in the estuary. Species of the family Acartiidae dominate the counts. Higher abundance of copepods are recorded during the saline summer period. The system remains practically virgin and underexploited at secondary level during low saline monsoonal period. Invasion of various species into the estuary and their succession begin by postmonsoon followed by diversification and habitat selections in premonsoon. Community structure and variations in diversity trends can be explained to some extent based on salinity distribution. Broadly, 3 seral stages can be recognised in the successional sequence consisting of high saline, low saline and medium saline species.

Copepods, by their sheer abundance and diversity constitute the most important group in any zooplankton community. They include mostly herbivorous and omnivorous forms along with some carnivorous species. They occupy an important position in the trophic structure and play a major role in the energy transfer of any aquatic environment. Because of their predominance, copepods form the chief index of utilization of biotope at secondary level. Some aspects of the ecology of estuarine copepods of India have been reported[1-7] Results of detailed studies on distribution of major species, community structure, diversity and species succession in Cochin backwaters are presented in this paper.

Materials and Methods

Zooplankton collections were made during day and night at barmouth, Cochin, Aroor and Narakkal (Fig. 1) every month from November 1971 to October 1972 (series A). Samples were taken with a HT net (mesh size 300 μ) in oblique hauls from bottom to surface lasting 5 min with a flow meter attached. Copepods and other zooplankton in each sample were counted to species level. Average numbers of day and night hauls were used. Aspects of another set of collections (series B) taken from mouth to head of the estuary in 1972 (ref.1) were also used as supplementary data to augment certain aspects of the results. Physical parameters of the environment such as salinity, temperature and oxygen were also recorded[8].

Results and Discussion

Community and abundance—Copepods were the most dominant group in the zooplankton of the estuary constituting 55 to 85% of the total annual zooplankton counts at the 3 stations (annual mean to total counts - 74.5%). They formed the bulk of the zooplankton biomass.

In the backwaters, 49 species of copepoda belonging to 22 genera were observed. Calanoid copepods comprising 41 species belonging to 11 families constituted the majority. Six species of cyclopoids

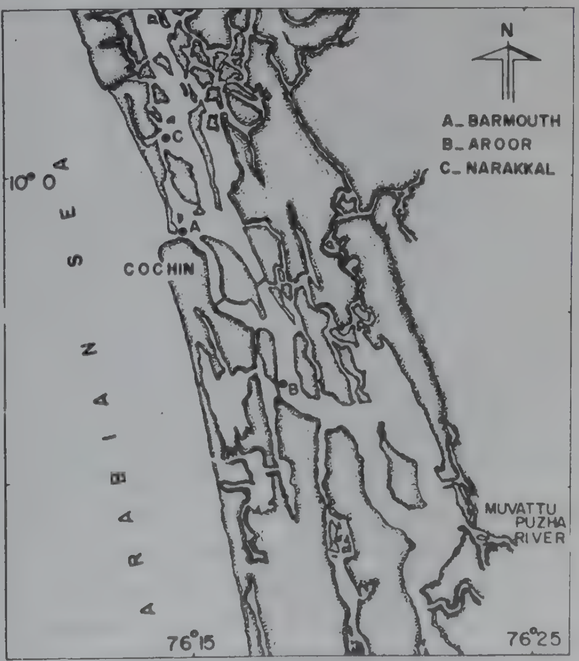

Fig. 1—Station location map

belonging to 3 genera and 2 genera of harpacticoids each represented by a species constituted the remainder of the composition. About 50% of the species occurred sporadically or in small numbers. Most species of copepods occurring in the estuary were listed[1]. The species not reported earlier were *Canthocalanus pauper*, *Undinula vulgaris*, *Eucalanus monachus*, *E. crassus*, *E. subcrassus*, *Calanopia elliptica*, *C. minor* and *Labidocera kroyeri* var. *gallensis* which are essentially marine forms and occurred at the mouth of the estuary occasionally. *Archidiaptomus aroorus* an interesting new pseudodiaptomid[9] and the hardy harpacticoid *Nitochra spinipes* which is seen mostly associated with the decays of the weed *Salvinia* flushed into the estuary by the monsoon.

Density of copepod population varied greatly with seasons (Table 1). Minimum densities noticed were 3, 10 and 1/m^3 at barmouth, Aroor and Narakkal respectively during monsoon season. Maximum densities went up to 18607/m^3 (night, April) at barmouth, 15021/m^3 (day, February) at Aroor and 4287 m^3 (night, March) at Narakkal. But in series: B, maximum density of copepod population observed was only 874/m^3 even though the period of sampling overlapped. This indicates the wide range of fluctuations of population possible in a complex aquatic environment like an estuary. Tranter and Abraham[5] also observed wide variations in copepod population in this estuary. The highest copepod density observed by them was 55390/m^3 at the middle reaches during postmonsoon whereas minimum density observed in the same season at a nearby station was only 2/m^3. Subbaraju and Krishnamurthy[10] observed the average copepod population from Vellar estuary on the east coast during summer months to be $>$ 100000/m^3 with maximum density as 286000/m^3. During the rest of the year also copepod densities were comparatively high in this water ranging between 30000 and 50000/m^3. Copepods constituted 90% of the zooplankton population in Porto Novo waters. Grindley and Wooldridge[11] have recorded high density (42700/m^3) of a single estuarine copepod *Pseudodiaptomus charteri* from Richards Bay, S. Africa.

Average copepod counts from the 3 stations were 1631/m^3 for the whole year, 4046/m^3 for premonsoon (January-April) 436/m^3 for monsoon (May-October) and 391/m^3 for postmonsoon (November-December). The apparent decrease during postmonsoon compared to monsoon season was due to the presence of higher densities of copepod population at the mouth during early monsoon period. The averages from the 2 stations inside the estuary showed copepod densities to be 84/m^3 for monsoon and 278/m^3 for postmonsoon.

Distribution and species associations—Greater abundance of copepoda was observed between February and April at the mouth and January to April at Aroor and Narakkal (Table 1). Thus, the distribution of copepoda showed higher abundance during the saline premonsoon period. The increase and decrease in their abundance was closely associated with the salinity intrusion in the estuary. Earlier observations[6,12] also showed salinity to be the chief factor controlling the zooplankton abundance in the estuary. During premonsoon, although a salinity gradient was present from mouth to the head of the estuary[13], the total counts of copepods over space were more or less uniform. This was possible because different species could fill the different niches owing to their differences in salinity tolerance and preference.

Table 1—Copepod Density (No./m^3) and Relative Percentage Based on Total Zooplankton Counts (1971-72)

Month	Barmouth		Aroor		Narakkal	
	D	%	D	%	D	%
Nov.	245	30.5	489	44.3	2	100
Dec.	979	59.7	607	66.7	12	40
Jan.	688	66.4	9109	81.6	974	52.8
Feb.	3300	81	10775	94.5	1147	61.3
March	3531	96.5	3460	87.8	2148	58.8
April	9890	95.5	2669	77.4	858	46.3
May	3590	89	176	58.6	8	53.3
June	523	96	267	56.5	45	56.9
July	2436	88.5	390	51.3	26	23.8
Aug.	3	0.5	74	56.4	1	50
Sept.	6	14	270	40.9	1	11.1
Oct.	285	50.5	10	62.5	86	48.5
Annual mean	2123	64	2328	64.9	442	50.2
Per cent to annual total		85.4		83		55.1

D = Density

Distribution of 17 more common species of copepods at the 3 stations are given in Fig. 2, and 13 of them over the whole estuary in Fig. 3. The salinity range in which the common species occurred and their salinity preference based on abundance are given in Table 2.

Acrocalanus similis, *Acartia bowmani*, *A. centrura* and *A. bilobata* were the most successful species in terms of abundance at the lower and later at lower middle reaches during saline period in the estuary. Of these, *Acartia* spp occurred at the mouth by October. By late postmonsoon (December) or early premonsoon (January) they flourished in the interiors of the estuary along with salinity incursion. *Acrocalanus similis* appeared in December and this species could also successfuly compete with other species present in the estuary during premonsoon. *Acartia spinicauda* also showed similar distribution, but was less abundant.

Another group which was also predominantly high saline consisted of species such as *Paracalanus aculeatus f. major*, *P. crassirostris f. cochinensis*,

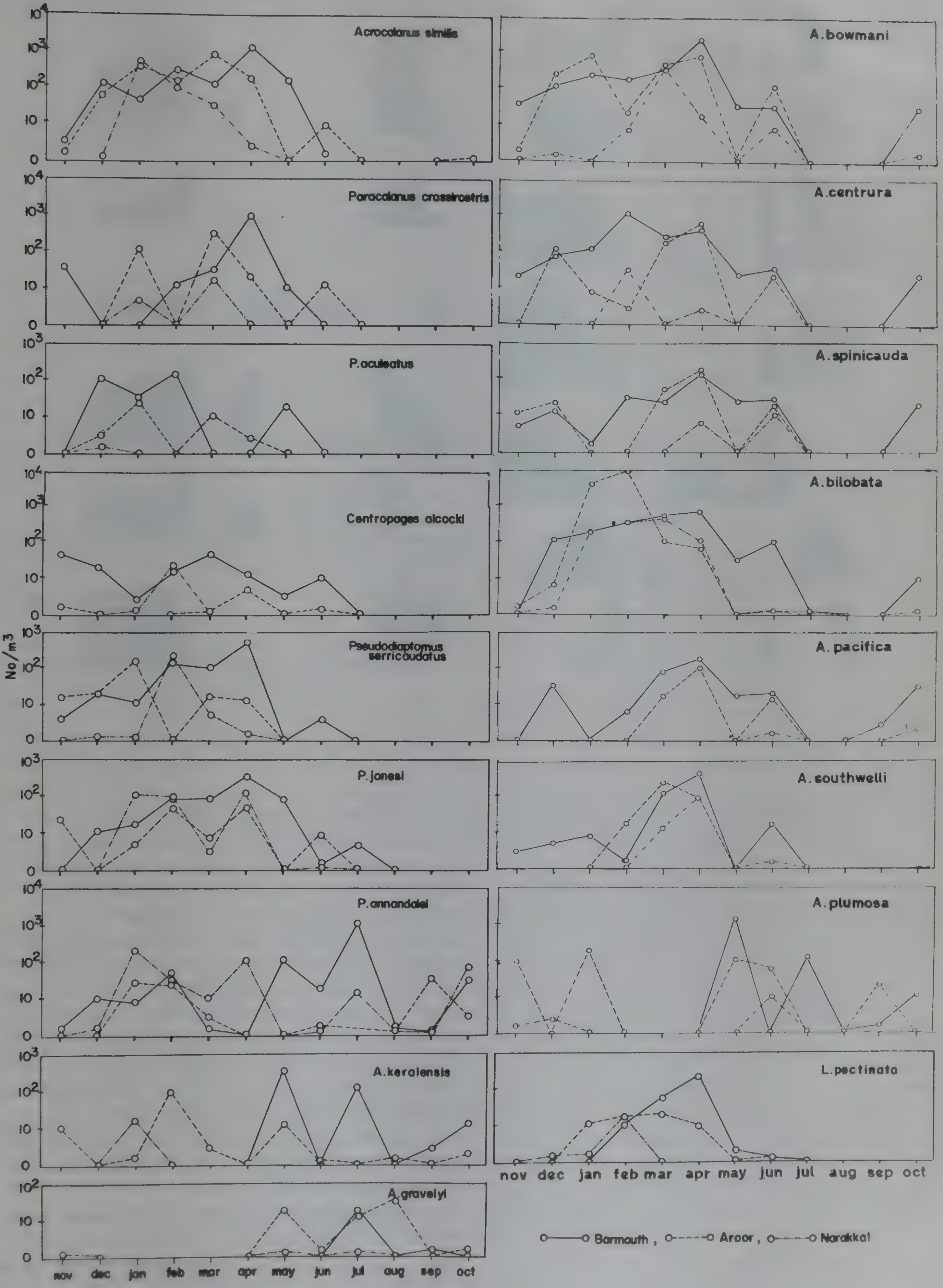

Fig. 2—Distribution of common species of copepods at barmouth, Aroor and Narakkal (1971-72)

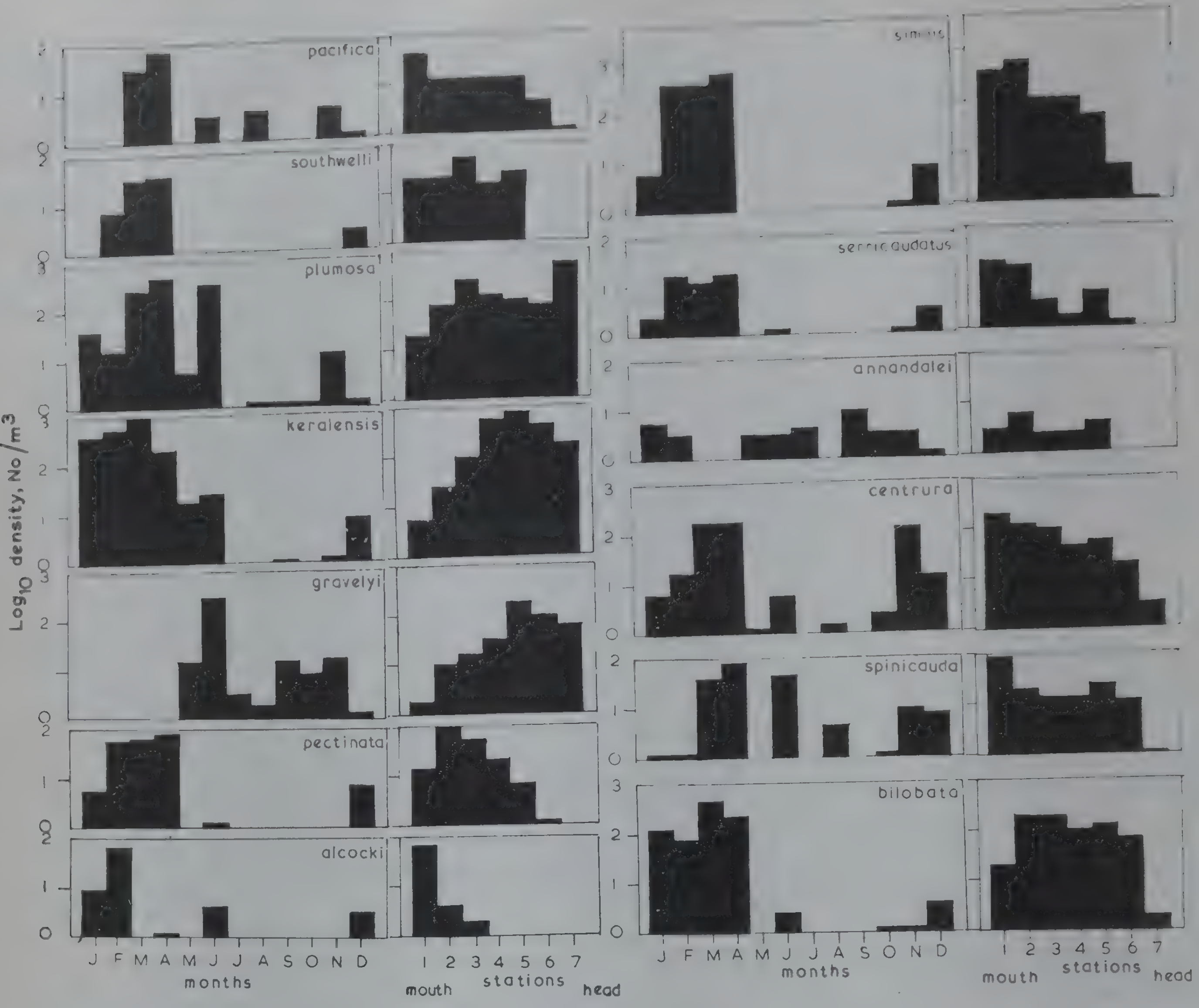

Fig. 3—Distribution of common species of copepods in time (1972) and space (Cochin to Alleppey)

Table 2—Maximum Salinity (‰) Range and Optimum Salinity for Major Copepod Species

Species	Maximum	Optimum
Paracalanus aculeatus	13.5-34.5	25.5-34.5
P. crassirostris	14 -34.7	28 -34.7
Acrocalanus similis	2 -35.6	25.5-33.5
Centropages alcocki	14 -35.5	29 -35.5
Heliodiaptomus cinctus	0 -11.5	0 - 1.5
Allodiaptomus mirabilipes	0 -11.5	0 - 1.5
Pseudodiaptomus annandalei	0 -35.2	5 -31
P. binghami malayalus	0 -10	0 - 2
P. jonesi	18.5-35.2	25.5-34
P. serricaudatus	13.4-35.5	25.5-34
Labidocera pectinata	2 -35.5	29 -35.5
Acartia centrura	5.8-35.2	26.5-33.5
A. bowmani	9.5-35.2	27.5-32
A. spinicauda	5.8-35.2	29 -33
A. plumosa	0 -28	15 -25
A. southwelli	17 -35.5	30 -35
A. pacifica	12.6-35.5	30 -35.5
A. bilobata	8.6-35.5	26 -34
Acartiella keralensis	0 -29.7	18 -26
A. gravelyi	0 -12	0 - 3

Pseudodiaptomus serricaudatus, P. jonesi, Acartia pacifica and *A. southwelli*. They also occurred in the estuary by postmonsoon. They had sudden peaks in abundance in certain months, but unlike in the previous group were not consistently abundant throughout the saline season. Variations existed in the distribution of species within this group. *Paracalanus crassirostris, Acartia pacifica* and *A. southwelli* were restricted to the mouth region during post-monsoon. Among the 2 species of *Acartia, A. southwelli* showed more restricted distribution and was not found beyond middle reaches unlike *A. pacifica. Pseudodiaptomus serricaudatus* and *P. jonesi* exhibited more or less similar pattern of distribution and *Paracalanus aculeatus* had more restricted occurrences. This species may be even grouped with the next category.

The 2 euryhaline marine species *Centropages alcocki* and *Labidocera pectinata* were common, but occurred in still lesser numbers. Except for these 2 species which propagated in the estuary, other species recorded from these 2 genera were only stragglers into the backwaters. Among the two, *C. alcocki* showed less tolerance to lower salinities (Table 2) and was restricted to the lower reaches of the backwaters.

Acartia plumosa and *Acartiella keralensis* preferred medium salinities. Although the 2 species were more abundant in the estuary during premonsoon they were absent at the mouth region during this season (Fig. 2). They were present at Aroor and middle reaches where salinity was not high during early premonsoon. When salinity registered higher values at these regions they shifted further up the estuary. The locality of their abundances oscillated with salinity vacillations. When monsoons started and upper reaches became fresh water, these species were observed at the mouth region. But later during the monsoon (August) they were absent at the mouth also.

Pseudodiaptomus annandalei exhibited a peculiar distribution. It had a wide range of salinity tolerance (0-35‰) and occurred in large numbers in various salinities. It occurred throughout the year, but in low numbers during the peak salinity months of March and April. It dominated some samples taken during monsoon period at the lower reaches. Inspite of its wide range of salinity tolerance this species did not occur at the upper reaches at any time during the year (Fig. 3). This species seems to prefer stratified waters of early premonsoon, monsoon and post-monsoon seasons present at the lower reaches[8]. Its salinity tolerance is probably used as an adaptation to survive in such conditions and to escape competition. But this species could not survive in total freshwater for long as they were always absent at the upper reaches which are shallow and remains fresh water from top to bottom for most part of the year. Salinity penetration reaches the upper reaches only by late premonsoon, but vertically homogenous conditions exist throughout the system during this period[13]. This explains its occurrence in low numbers during this period and exclusion from the upper reaches throughout the year.

Heliodiaptomus cinctus, Allodiaptomus mirabilipes, Archidiaptomus aroorus, Pseudodiaptomus binghami malayalus, P. tollingarae and *Acartiella gravelyi* were the low saline calanoid copepods present in the estuary. Of them *A. gravelyi* was the only species that successfully flourished during the monsoons. It was present at the mouth only during the peak of the monsoon (July) when salinity was low. It dominated the copepod counts during low salinity regime. Other low saline species occurred only in small numbers.

Among the cyclopoids, *Oithona* spp were common in the estuary. *O. rigida* was frequent during high saline period. *O. brevicornis, O. hebes* and *O. nana* were more tolerant to lower salinities, the last two more so than *O. brevicornis.*

Family Acartiidae contributed to the majority of copepod counts in the estuary (Fig. 4). Ten species were recorded from the backwaters, the diversity of the family is higher than that found in any other area in the world. Family Pseudodiaptomidae ranked next by having 8 species. But next to Acartiidae family Paracalanidae dominated the copepod counts during premonsoon. Whereas families Acartiidae and Pseudodiaptomidae had low saline species to replace the high saline ones during monsoonal period, the abundance of species of the family Paracalanidae dwindled during this span.

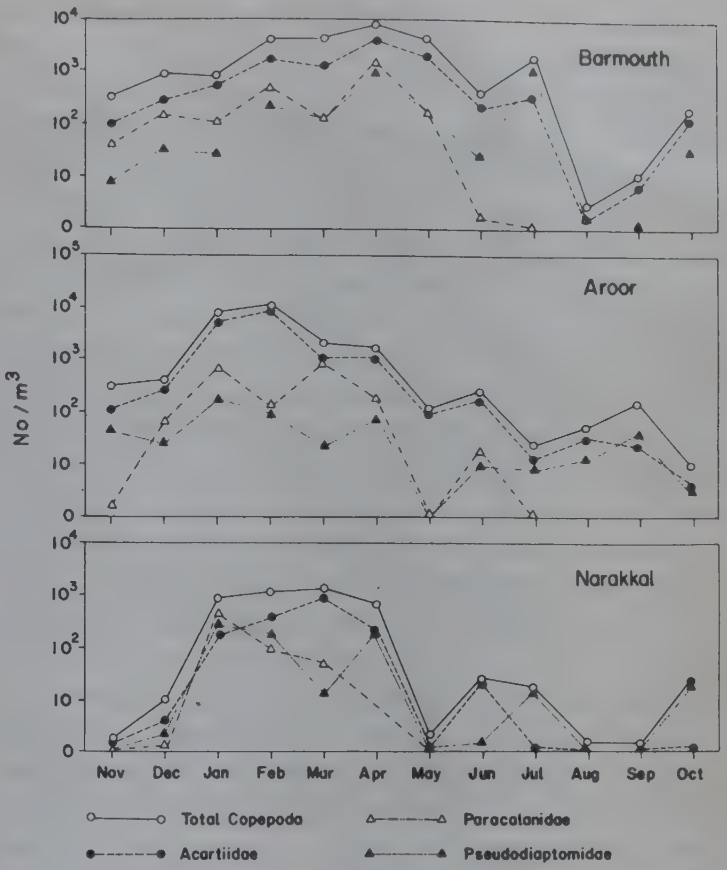

Fig. 4—Distribution of the major families of copepods at barmouth, Aroor and Narakkal (1971-72)

Species of the family Acartiidae are well adapted to estuarine conditions and are found in the estuaries throughout the world. Experimental studies have shown that *Acartia tonsa, A. bifilosa* and *A. discaudata* are able to withstand considerable salinity variations[14]. *Acartia* probably attains dominance in brackish waters because low salinity excludes the more metabolically efficient oceanic species[15]. *Acartia* is the most common calanoid copepod of Southampton waters[16]. *A. clausi* and *A. tonsa* dominate the zooplankton of New England estuaries[17]. Species of *Acartia* and *Pseudodiaptomus* have been reported to constitute the majority of zooplankton in Richards Bay, South Africa[11]. In the east coast of India *Acartia* spp are common in the Godavari estuarine system[18]. But *Oithona* have been reported as the dominant copepod in the Vellar-Coleroon estuarine system although some 7 species of Acartiidae have been recorded from this area[10].

The common copepod species of the Cochin backwaters exhibit a wide range of salinity tolerance (> 34‰). Of them only *Centropages alcocki*, *Labidocera pectinata* and *Paracalanus* and *Acrocalanus* spp are common in the coastal waters. Other common high saline species of the estuary belonging to families Acartiidae and Pseudodiaptomidae except *Pseudodiaptomus serricaudatus* are rare in the coastal waters of Cochin area[19]. The species which were only stragglers into the estuary are common in the inshore waters. Grindley and Wooldridge[11] have found that the salinity tolerance of Pseudodiaptomid species of Richards Bay ranged from nearly freshwater to 60‰ and peak survival at approximately 35‰ salinity and that these species do not occur in normal sea water. They believe that it is not salinity but competition from marine organisms that prevent them from surviving in the sea, whereas their adaptation for surviving extreme environmental fluctuations allow them to flourish in the estuary. This seems to be applicable here also. Similarly competition must be the factor which prevents survival of the numerous coastal water species in the estuary although salinity is comparably high at the lower reaches during premonsoon.

Diversity—Diversity indices at the 3 stations were calculated using the formula of Fisher *et al.*[20] and are given in Fig. 5. The variations occurring in diversity could be explained to some extent based on salinity fluctuations. Although subject to constant changes owing to tidal mixings, some semblance of stability in the estuary is developed during the salinity regime and a higher diversity was maintained during this period. The increase shown at Narakkal in June and at the mouth in June and September corresponded with an increase in salinity during monsoonal period. At the mouth a higher diversity occurred from January to June but at the stations inside the estuary it gradually increased with increase of salinity and a drop was observed by May when the monsoons started.

It is generally accepted that stability increases diversity. Tropical estuaries have more of physically controlled than biologically accommodated communities[21] and have less diverse communities than tropical marine environment. The total diversity of a community is a function of niche development and may therefore increase or decrease at various stages[22]. The premonsoon period although stabler is too short to develop high diversity comparable to the marine environment. Thus the species that operate in the estuary during this season have broad niches and utilizing their adaptability to adjust to the fluctuating environment extract the maximum from it within the available period. A progressive diminution of index values observed from mouth to head of the estuary[6] indicates a less exploited biotope towards the upper reaches resulting from the delay or gradient developed in salinity incursion.

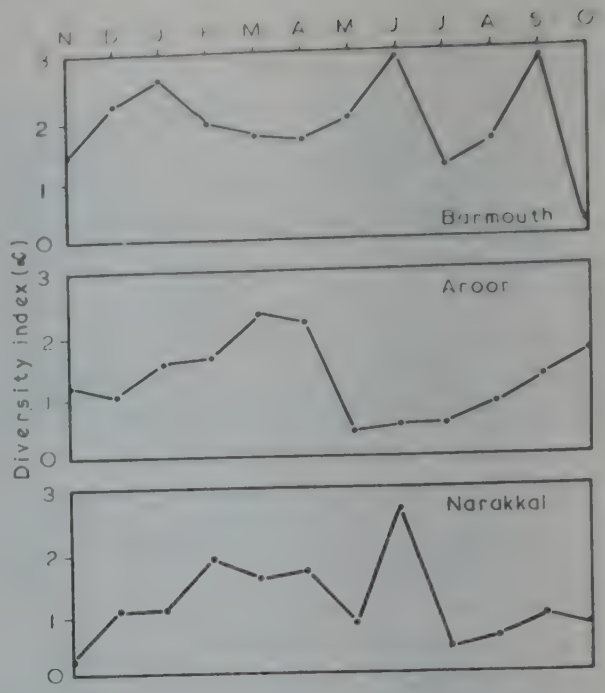

Fig. 5—Trends of diversity of copepods at barmouth, Aroor and Narakkal (1971-72)

Various hypothesis and theories involving time, spatial heterogenity, competition, predation, stability and productivity have been proposed to explain gradients in diversity. But pinpointing the reasons for the lack of diversity is difficult. "Niches can be defined only in retrospect, because the niche of any species has biotic dimentions determined by evolution"[23]. Spatial heterogenity is not wanting in the backwaters. Primary food is also available in plenty in the system[24]. The cause for the absence of enough species to exploit different situations especially low saline period is to be looked elsewhere. Lack of stability, time to diversify and physiological stress imposed by the environment should be the main reasons.

Species succession—Depending on the environmental parameters various species occur and propagate in the estuary, attain ascendancy and disappear during unfavourable conditions. Species succession which begins in the postmonsoon months along with salinity recovery varies with space and time and can be gathered from the numerical dominance exerted by various species.

The conspicuous feature over space (Fig. 6 b) was the dominance of the 2 medium salinity species *Acartiella keralensis* and *Acartia plumosa* in the middle and upper reaches of the estuary during the saline period. Although species like *Acartia bowmani*, *A. centrura*, *A. bilobata* and *Acrocalanus similis* did penetrate up to the head along with salinity incursion and usually dominated the faunal component at the lower reaches, they could not dominate. Had the salinity in these areas increased further by some

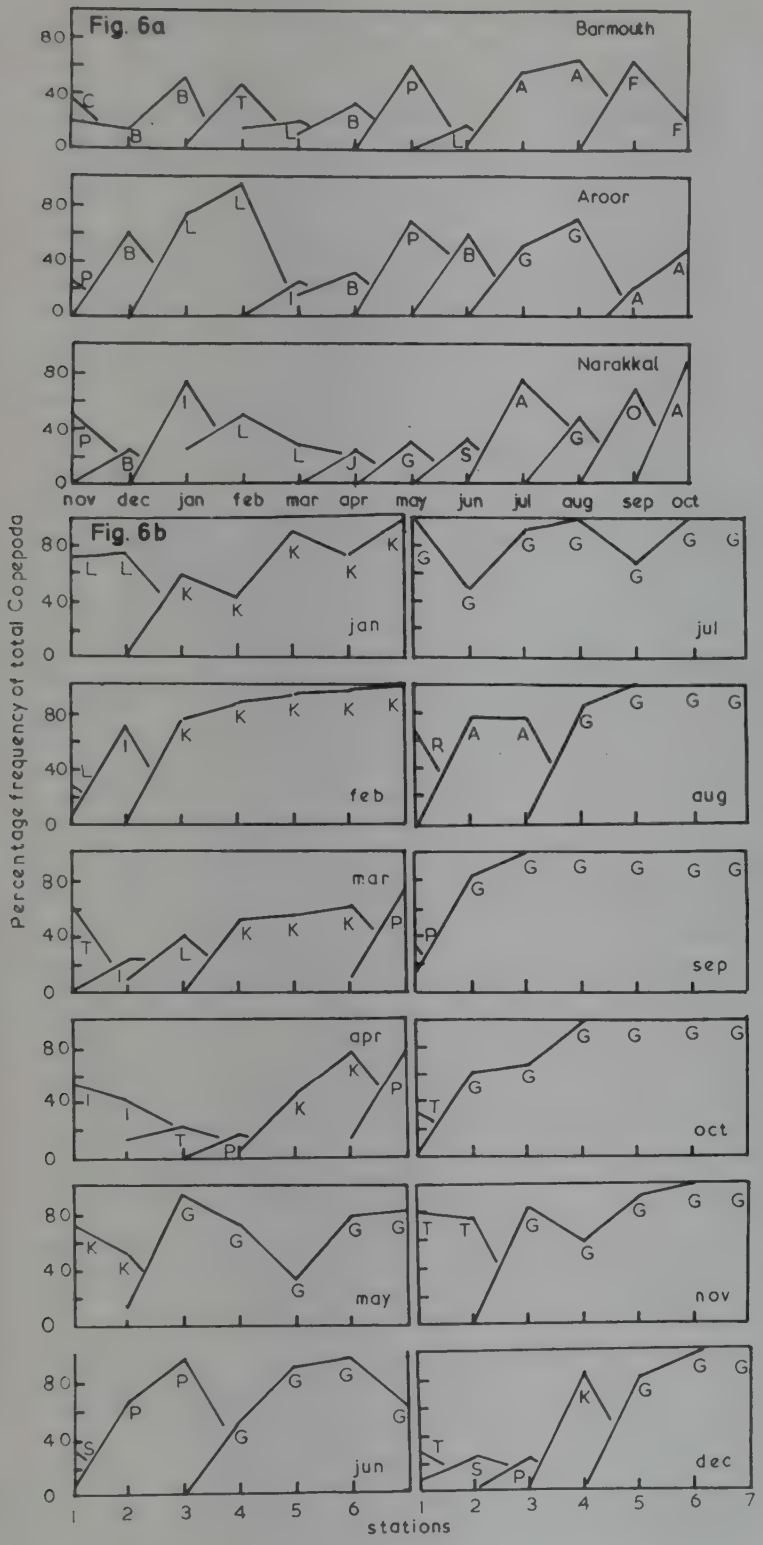

Fig. 6—(a) Succession of dominant copepod species at barmouth, Aroor and Narakkal [A—*Pseudodiaptomus annandalei*, B—*Acartia bowmani*, C—*Paracalanus crassirostris*, F—*Acartia pacifica*, G—*Acartiella gravelyi*, I—*Acrocalanus similis*, J—*Pseudodiaptomus jonesi*, L—*Acartia bilobata*, O—*Oithona brevicornis*, P—*Acartia plumosa*, S—*Acartia spinicauda*, and T—*Acartia centrura*]
(b) Succession of dominant copepod species from head to mouth of the estuary (series: B) from January to December 1972 [G—*Acartiella gravelyi*, I—*Acrocalanus similis*, K—*Acartiella keralensis*, L—*Acartia bilobata*, P—*Acartia plumosa*, S—*Acartia spinicauda*, R—*Centropages tenuiremis*, T—*Acartia centrura*]

mechanism (like a failure of monsoon) it is concievable that they would have dominated in these regions also. But by April they could exert their dominance only up to station 3 when monsoons inundated the estuary and the low saline species *Acartiella gravelyi* became the dominant copepod. In the postmonsoon months (November, December) the succession of high saline and medium saline species started from the lower reaches. Here (Fig. 6 a) high saline species dominated the counts during premonsoon and during the monsoon *Acartiella gravelyi* and *Pseudodiaptomus annandalei*, a copepod which prefers stratified water, usually dominated the zooplankton. It could be seen that the percentage of dominance attained by a species during salinity regime was not high unlike low saline period indicating that other species were also abundant in the composition.

Broadly, 3 seres could be recognised in the successional squence consisting of high saline, low saline and medium saline species. The redundance and dominance exerted by any sere at any time or place would depend on salinity incursion, fresh water efflux and resultant changes of salinity values. Most of the common species that occurred during high saline period were able to tolerate considerable range of salinity variations, but dominance seems to be achieved with optimum values. Among species with more or less same optimum salinity ranges, other factors such as metabolic requirements, competition, reproductive rate, etc. could be controlling factors.

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Tidal & Diurnal Influence on Estuarine Zooplankton

M MADHUPRATAP & T S S RAO
National Institute of Oceanography, Dona Paula, Goa 403004

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Observations made at the mouth of Cochin backwaters show that tidal variations are not much pronounced for most groups and species of estuarine zooplankton. The zooplankton seem to be able to maintain their position within the estuary during tidal exchanges. It is also possible that population of common species which extends over a large area during the period of their abundance oscillates so that the total picture of distribution remains largely the same, although individuals get shifted with tidal motions. Gradual oblique hauls from bottom to surface give a fairly accurate picture of the total zooplankton population irrespective of the time of collection in the deeper parts of the estuary. Vertical migration pattern shows that only a part of the population moves towards the surface during the night. Presence of low saline water in the surface layers inhibits vertical migration of high saline species.

Information available on tidal and diurnal variations of zooplankton from tropical waters, especially estuaries is meagre. Tides have profound influence on physical, chemical and biotic components of the estuary. Diurnal differences in zooplankton are mainly caused by vertical migration, the cause of which is chiefly attributed to responses of zooplankters to variations in light intensities. Reported studies include variations of zooplankton abundance over a tidal cycle from Godavari estuary[1] and Cochin backwaters[2]. Results of data collected for 1 yr from Cochin backwaters and statistically treated to study significant diel and tidal variations and vertical migration of zooplankton are presented here.

Materials and Methods

Zooplankton was collected from the mouth of Cochin backwaters (depth 12 m) once every month from November 1971 to October 1972. Four collections covering 2 high and 2 low tides were taken on each occasion using a Heron-Tranter (HT) net (mouth area – 0.25 m^2, mesh size – 300 μ) in gradual oblique hauls from bottom to surface lasting 5 min with a flow meter attached. Sampling was done at the peak of the high or low tide. In addition, horizontal tows were made at surface and bottom (6 to 7 m, bottom samples were also taken according to salinity stratification whenever present) lasting 15 min with a Clark-Bumpus net (mesh size – 300 μ). Samplings were also conducted at Aroor, about 14 km south of barmouth (depth – 7 m) and Narakkal, 10 km north of bar mouth (depth – 3 m) during day and night on days subsequent to collection at the mouth with HT net as previously mentioned. Salinity and temperature values for each metre depth were recorded with a salinity-temperature bridge. Zooplankton in each sample were counted to group and species levels. HT net data from the mouth were subjected to analysis of variance to study diurnal and tidal variations and from the other 2 stations for diurnal differences. Critical difference was used to separate the significant effects.

Results and Discussion

Tidal variations—Analysis of variance was performed for 12 groups and 33 species of zooplankton in addition to their total numbers and biomass and data of only significant groups and species included in Table 1. The results revealed that tidal variations were not very pronounced for the zooplankton component at the mouth of the estuary. Variations were significant only for a few species viz. *Pleurobrachia globosa*, *Acrocalanus similis*, *Centropages alcocki* and *Acartia plumosa*. At high tide the first 3 species which are euryhaline marine were abundant. *Acartia plumosa* was more abundant during low tide. This is because it thrives in medium salinity conditions and its population which was abundant towards the middle and upper reaches of the estuary during premonsoon period drifts down to the mouth with the onset of the monsoon during low tide. This species occurred at the mouth only during the early monsoon period when the upper reaches became totally fresh water and salinity at the mouth region was reduced to levels acceptable to it. Tidal variations were not significant for the other groups and species of zooplankton.

Someoto[3] has observed a periodic fluctuation correlated with tide for zooplankton biomass and

Table 1—Results of Analysis of Variance of Groups and Species

Source	Barmouth		Aroor	Narakkal
	Tidal	Diel	Diel	Diel
Total biomass	—	—	—	a(N)
Groups				
Mysidacea	—	c(N)	b(N)	a(N)
Amphipoda	—	c(N)	c(N)	b(N)
Zoea larvae	—	—	—	b(N)
Species				
Eirene ceylonensis	—	—	b(N)	—
Blackfordia virginica	—	—	c(N)	—
Pleurobrachia globosa	a(HT)	—	b(N)	—
Sagitta bedoti	—	—	—	a(N)
Acrocalanus similis	b(HT)	—	—	c(N)
Centropages alcocki	b(HT)	—	—	—
Pseudodiaptomus jonesi	—	—	—	a(N)
P. annandalei	—	—	—	c(N)
A. centrura	—	—	—	a(N)
A. spinicauda	—	—	—	c(N)
A. bilobata	—	—	—	b(N)
A. southwelli	—	—	—	c(N)
A. plumosa	a(LT)	a(D)	—	—
Oithona rigida	—	—	—	b(N)
Lucifer hanseni	—	—	—	c(N)

Significant at: a—5% level; b—1% level; c—0.1% level; —, not significant

Maximum abundance given in parenthesis: D—Day; N—Night; HT—High tide; LT—Low tide

several copepod species from St. Margaret's Bay, but the diurnally migrating zooplankton did not show a tidal correlation. Pillai and Pillai[2] have also observed variations in the biomass in the surface waters of Cochin backwaters associated with tides. No doubt, tidal exchanges contribute much to the exchange of water and recruitment in the estuary, but it would seem that the zooplankters are able to adjust and maintain their position within the estuary during tidal motions.

Slobodkin and Sanders[4] state that if the changes in an environment are predictable such as the tidal changes in an estuary, the inhabiting animals may develop behavioural mechanisms in response to tidal changes which keep them in the water of same salinity throughout the tidal cycle by having some kind of biological clock or a signal. Since there was no appreciable salinity changes in Cochin estuary during premonsoon months when the zooplankton was abundant[5], such behavioural responses may not be important except when stratified conditions occur. Another possibility is that although some individuals of species are carried away with tidal currents, other individuals of the population of the common species which extend over a large area in the estuary may replace them so that the numerical abundance would remain roughly the same over a period in a particular area.

Diurnal variations—Analysis of variance for diel variations at the 3 stations (Table 1) showed that significant variations were more common at Narakkal than at the other 2 stations. Here the zooplankton biomass and abundance of groups such as amphipoda, mysidacea, zoea larvae and the species *Sagitta bedoti*, *Acrocalanus similis*, *Pseudodiaptomus jonesi*, *P annandalei*, *Acartia centrura*, *A. spinicauda*, *A. bilobata*, *A. southwelli*, *Oithona rigida* and *Lucifer hanseni* were significantly higher during night than during day. This station is shallow and the high illumination of the water column probably drives the zooplankton to take refuge very close to the bottom or in the bottom mud during the day time. However, the other 2 stations are comparatively deeper and zooplankton can escape to the more optimal light intensities towards the bottom layers of the water column. HT net hauls were taken from bottom to surface and this accounted for the lack of marked diel variations at the other 2 stations. This also indicates that such hauls give a reasonably uniform picture of the zooplankton population in such deeper parts of the estuary irrespective of the time of collection.

Amphipoda and mysidacea exhibited significant diel variations at all the 3 stations. They, especially the latter appear to come out into the water column from the mud only during night. This has been observed for Cumacea, Mysidacea and crab megalopae from Southampton waters[6]. *Acartia plumosa* was more abundant during day time at the mouth, but their occurrence at this station seems to be controlled by tides.

Vertical migration of zooplankton groups and species was assessed from their density distribution (averages) at the surface and bottom layers in day and night observed from the Clark-Bumpus hauls (Figs. 1 and 2).

Higher concentration of almost all species of zooplankton occurred at the surface during night when compared with day time. But the concentration of larvae showed a difference in the pattern. Caridea larvae, cirripede larvae, fish eggs and fish larvae showed slightly higher densities at the surface layer both during day and night. But among them cirripede larvae and fish eggs and crab zoea showed more or less uniform depthwise distribution irrespective of time. Increase in densities at surface layer during night was shown by all the species except *Acartia plumosa* and *Acartiella keralensis*. A sharp decrease in densities at bottom layers during night was shown only by a few species. Most species like *Acrocalanus similis*, *Pseudodiaptomus serricaudatus*, *P. annandalei*, *P. jonesi*, *Centropages alcocki*, *Acartia centrura*, *A. bowmani*, *A. spinicauda* and *A. bilobata* and groups such as fish eggs, copelata, amphipoda, cirripede larvae

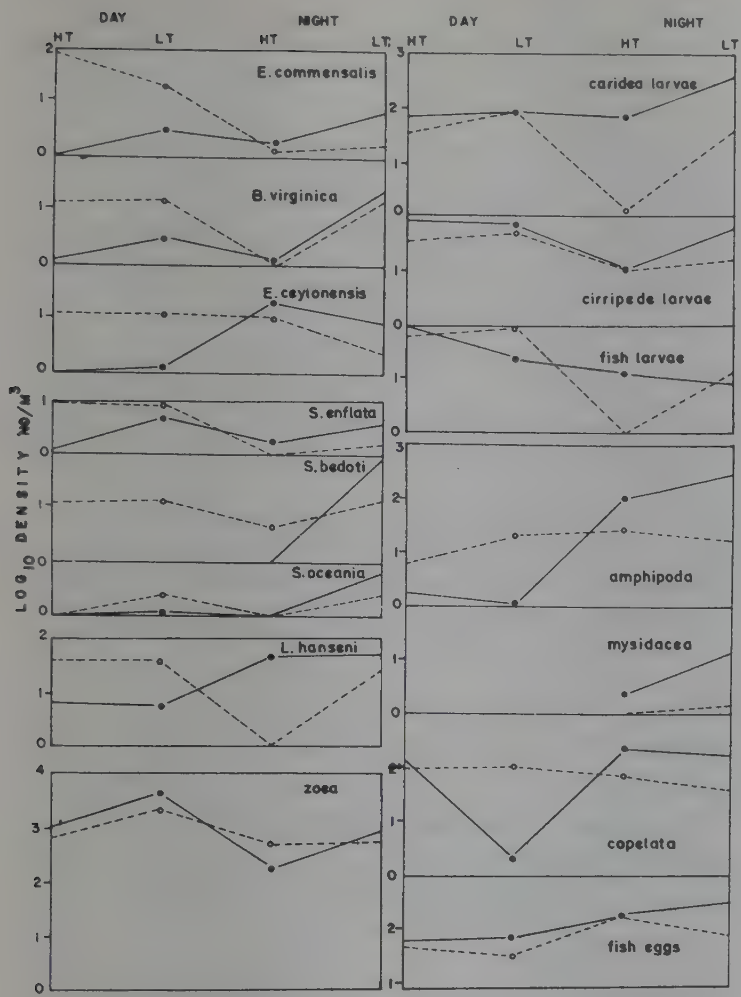

Fig. 1—Average density distribution of hydromedusae, chaetognatha, *Lucifer*, invertebrate larvae, fish eggs and larvae and other groups of zooplankton at barmouth, Cochin [At surface (–) and bottom (---). HT—High tide, LT—Low tide]

and zoea showed more or less uniform densities at bottom layers during day and night. Thus, the pattern of vertical migration did not indicate a complete movement of whole plankton population but rather a tendency of part of the population to spread towards surface at night.

Acartia plumosa and *Acartiella keralensis* showed higher concentration at the mouth in the bottom layers both during day and night. This was because these 2 species shifted to the mouth region only during monsoon season when salinity in the interior of the estuary became too low for their survival. But at the mouth also salinity was low at the surface layers. Hence these species were confined to the bottom layers during night also. Distribution confined to bottom layers during night when surface salinity was low at the mouth in May was observed for other high saline species like *Sagitta bedoti*, *Acrocalanus similis*, *Acartia centrura*, *A. bilobata*, *Pseudodiaptomus jonesi* and Hydromedusae. The presence of low saline water at the surface inhibited the vertical migration of estuarine zooplankton in River Test at Southampton[7].

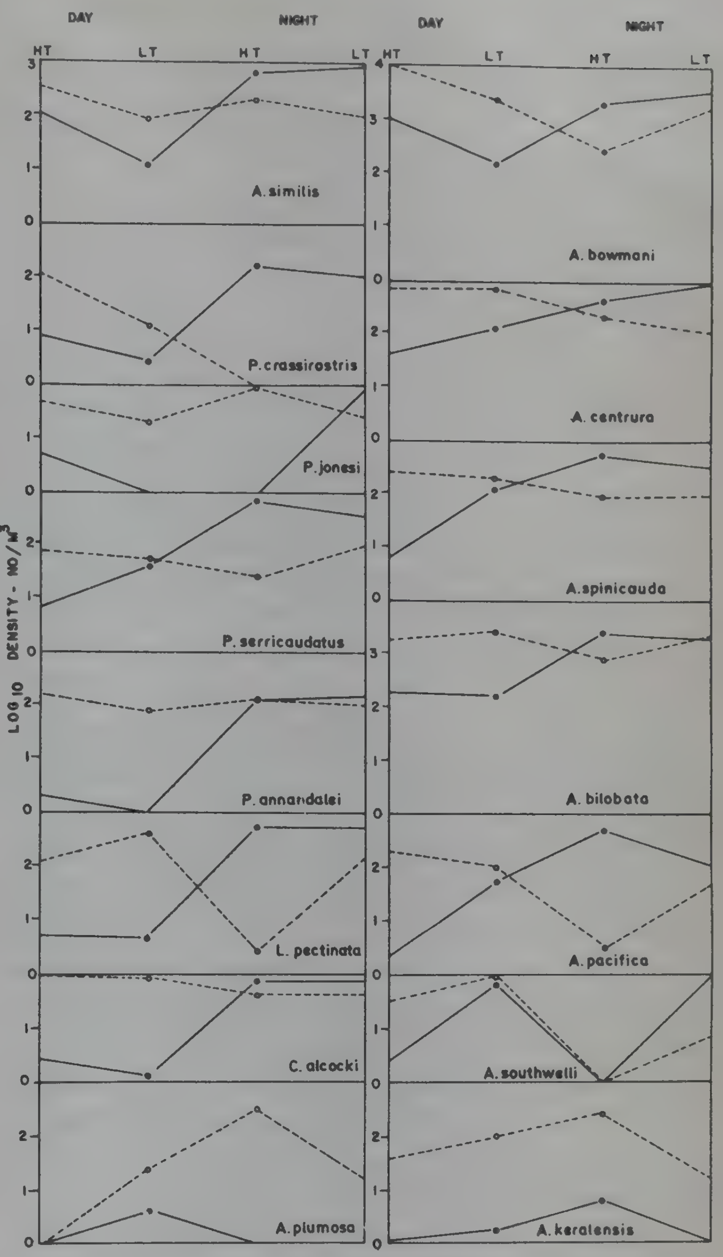

Fig. 2—Average density distribution of different species of Copepods at barmouth, Cochin at surface (—) and bottom (----)

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Growth Studies on *Clypeomorus clypeomorus* Jousseaume (Gastropoda : Cerithiidae) from the Visakhapatnam Coast

L MANMADHA RAO & D V RAMA SARMA
Department of Zoology, Andhra University, Waltair 530003

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Growth rate of *C. clypeomorus* has been measured employing analysis of population sampling and calculation of absolute growth rate. Height and age relationships of the snail are studied. Results show clear seasonal variation in growth rate of the snail, maximum shell height of 18 mm and survival period of 1 yr. It attains sexual maturity at shell height of 11-12 mm and breeding is continuous. The small size and relatively short life span may be due to early attainment of maturity and continuous reproductive activity.

Investigations have been made on the growth rate and the effect of growth on the shape of the shell in different molluscs[1-9]. Population sampling and absolute growth rate methods are important among the various methods[8,10-14] employed in the growth rate studies of molluscs. An attempt has been made here to study the growth rate in *Clypeomorus clypeomorus* Jousseaume employing both population sampling and absolute growth rate methods. Attempts have also been made to follow the height and age relationships and the changes in the form of the shell with growth of the animal.

Materials and Methods

Monthly observations were made during September 1974 to August 1975. Animals were collected at random from a unit area (1 m^2) at mean low water neaps. Different parameters such as shell height and breadth, width of the opening and height of the spire were measured to the nearest millimetre with a vernier calipers. The data thus obtained were used to draw the monthly height frequency distribution of the collection. Growth rate was determined from the shift in the modal length. Monthly mean values of the shell height were plotted to show the monthly population growth.

Absolute growth rate was studied by the method of Ward[8]. Observations were made in the laboratory on snails of 6 size groups (6,7,8,9,10 and 11 mm) employing 10 animals in each. Animals of each size group were placed separately in glass troughs (2 l). Small stones with the alga *Chaetomorpha*, collected from the same habitat of the snails, were placed in the troughs. Sea water was replaced once in every 24 hr.

Measurements were taken at monthly intervals and the mean shell height in each size group was calculated. These observations were made for 2 months only as the animals did not survive any longer under laboratory conditions.

To determine the composite picture of growth the above data were first plotted as the regression of height at time $t+1$ on height at time t using the equation

$$H_{t+1} = mH_t + i \qquad \text{... (1)}$$

where m is the slope of the line and i the vertical intercept[15,16]. As a second step towards determining the height and age relationship of the snail von Bertalanffy[17] growth equation was used.

$$H_t = H\infty \ (1\text{-}e^{-k(t-t_0)}) \qquad \text{... (2)}$$

where $H\infty$ is the asymptotic height, k the growth coefficient and t_0 the theoretical age at height zero. The other details in the methods employed are given at relevant places.

To study the changes in the shape of the shell as the snail grows in size, the method adopted by Russel[1] in *Patella vulgata* and Abe[5] in *Acmaea dorsuosa* was followed. Ratios of shell height to shell breadth, shell height to width of the aperture and shell height to height of the spire were calculated. Only the means of these ratios were taken for the presentation of the data. Mean ratios were arranged in 3 mm height groups to study variations in the form of the shell as the animal increases in height.

Results

Analysis of population—A total of 1200 (100 in each month) animals have been examined from September 1974 to August 1975. The shell height frequency for different months is illustrated in Fig. 1. The age classes in the population of *C. clypeomorus* are not distinctly clear. However, the presence of 2 modes in some of the samples suggests that there is more than one age group in the population. It is clear that young animals get added resulting in a numerical increase of the population in November and May, and many old well grown shells consequent on the death of snails harbour hermit crabs. The younger animals attain their breeding size within 5 months and start breeding soon after. The mean shell heights of various months are presented in Fig. 2. The mean shell height of the population in September is 14.94 mm. In October it reaches maximum of 15.84 mm. In November as more young animals are added to the population and as the older die off, mean shell height has dropped to 12.5 mm. In December there is a further decrease in the shell height to 11.6 mm due to the addition of younger animals in increased numbers. Later there is a gradual increase in the shell height up to April. The mean shell height has again fallen to 11.8 mm in May due to the addition of young animals to the population. Thereafter, there is a gradual increase. It is clear from Fig. 2 that the number of animals of larger size increase once in September-October and again in March-April. Large number of animals are added to the population twice a year, once in November and again in May.

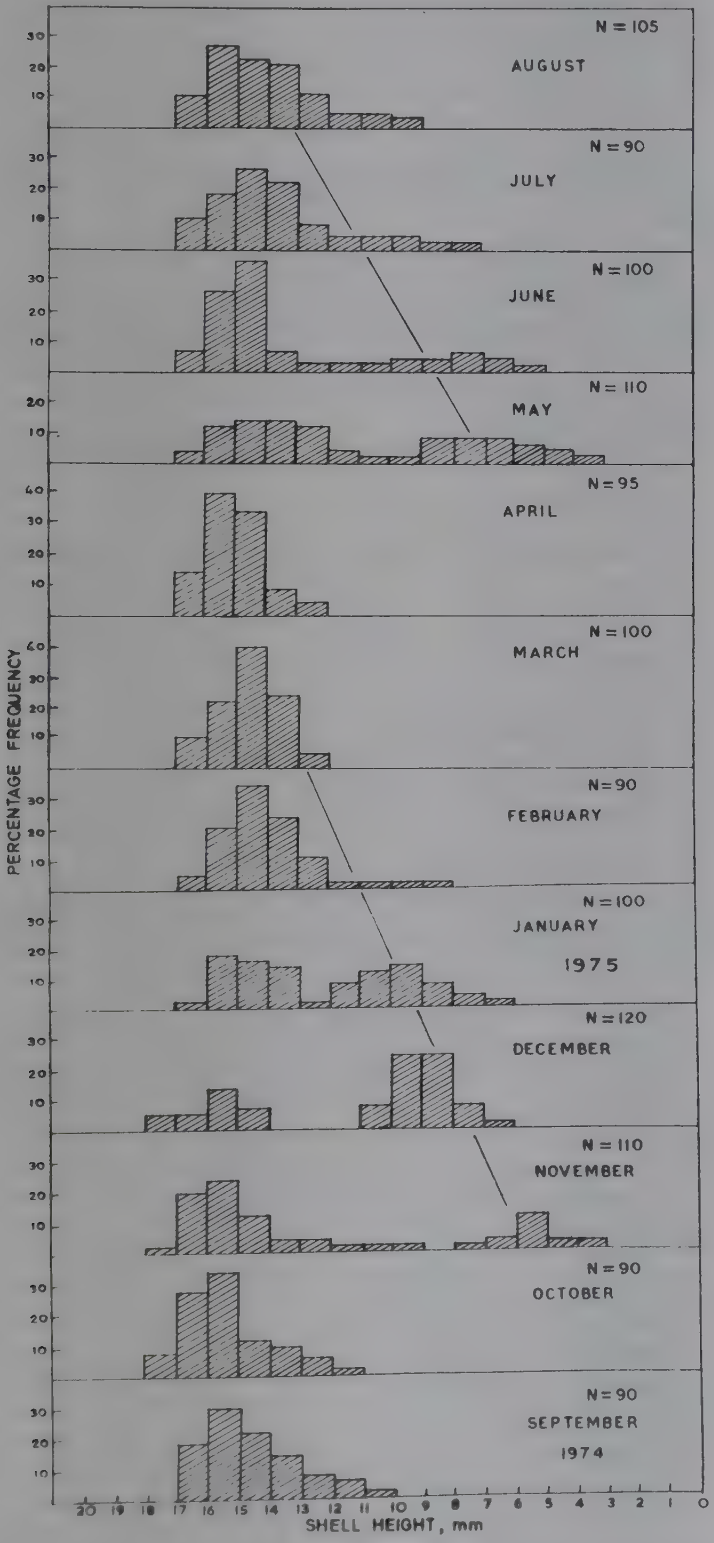

Fig. 1—Shell height frequency distribution of *C. clypeomorus* from September 1974 to August 1975

Growth curves (absolute growth)—Results of observations made on the absolute growth rates of the snail are presented in Tables 1 and 2. Mean shell heights in the 6 size groups increase progressively from November to January with an average monthly increment of 1 mm.

To obtain a composite picture of growth the results of absolute growth rates were first plotted as the regression of the height at time $t+1$ on height at time t using the eq. 1. Values of H_t and H_{t+1} in the equation can be obtained directly from the results of absolute growth rates in Table 1. The values thus obtained are given in Table 2. The constants m and i, calculated by the method of least squares, are 0.8714 and 2.2429 respectively.

The relationship between H_{t+1} and H_t is linear and the line describing the relationship intercepts the 45° diagonal at an H_t value of 17.6 mm. This value is an estimate of the maximum theoretical height which *C. clypeomorus* can possibly attain and it coincides fairly closely with the field observations. The maximum shell height recorded in the course of this study is 18 mm.

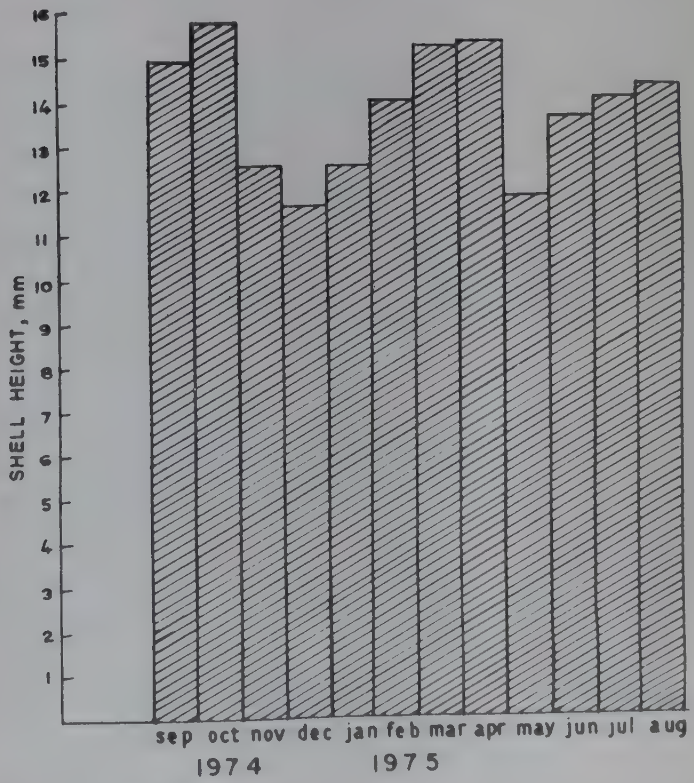

Fig. 2—Mean shell heights of *C. clypeomorus* in different months

Table 1—Absolute Growth in Shell Height of Different Size Groups

[Number of animals in each size group is 10]

Size group	Height of shell in November (mm)	Av. increment in shell height (mm)	
		December	January
1	6	1.5	1.2
2	7	1.3	1.1
3	8	1.2	1
4	9	1.1	0.9
5	10	1	0.8
6	11	0.8	0.7

Table 2—Values of H_t and H_{t+1}

H_t (mm)	H_{t+1} (mm)	H_t (mm)	H_{t+1} (mm)
6	7.5	9.2	10.2
7	8.3	10	11
7.5	8.7	10.1	11
8	9.2	11	11.8
8.3	9.4	11.8	12.8
9	10.1		

As a second step towards determining the height and age relationship of the snail eq. 2 was used. $H\infty$ and k in the equation can be obtained as $H\infty = i/(1\text{-}m)$ and $k = (\text{-}\log_e m)$ and the values calculated are 17.66 and 0.3119 respectively. As for the other parameter t_0 to be calculated in the equation, Ward[8] found that t_0 in the key-hole limpet, *Fissurella barbadensis*, is negligible. Similar observations were also made by others[18,19].

In *C. clypeomorus* the age cannot be obtained from the annual rings because of the continuous and slow growth of the snail. Direct observation on the newly settled snails is not possible as the veliger larvae failed to settle in the laboratory aquaria. However, there are indications (Table 1) that the growth rate in the early stages is very rapid suggesting that t_0 is negligible in this snail.

The estimated growth in terms of various parameters is given in Table 3. The relationship between height and age of the snail indicates that the growth of *C. clypeomorus* occurs in a sigmoid fashion. Further, it indicates that the snails attain the maximum shell height of 17.5 mm within 12 months of age and hence it may be presumed that the life span of *C. clypeomorus* is about 1 yr.

Relative growth—After determining the growth rate of shell height, the increments in different shell dimensions have been calculated by linear regression equations using the method of least squares. In the present study the following relationships are described: Shell height/shell breadth; shell height/width of the opening; and shell height/height of the spire. Average breadth, width of the opening and height of the spire of various size groups during the study period are given in Table 4.

Shell height/shell breadth: Relation between the shell height and shell breadth is linear and the regression equation for this is

$$B = 0.65\ H - 0.27$$

where B is breadth and H shell height in mm.

Shell height/width of opening: Mean widths of the opening against the mean shell heights showed a linear straight line regression and the equation for the above relationship is

$$WO = 0.36\ H - 0.13$$

where WO is width of the opening and H shell height in mm.

Shell height/height of spire: Mean heights of all the spires against the mean shell height also showed a linear relationship and the regression equation for this is

$$S = 0.60\ H - 0.33$$

where S is height of the spire and H shell height in mm.

Table 3—Estimated Growth (mm) in Various Parameters

Age (months)	Shell height	Shell breadth	Width of opening	Height of spire
2	7.9	4.9	2.7	4.4
4	12.35	7.7	4.3	7.1
6	14.7	9.3	5.2	8.6
8	16.2	10.2	5.7	9.5
10	16.9	10.6	6	9.9
12	17.2	10.8	6.1	10.1

Table 4—Average Breadth, Width of Opening and Height of Spire of Various Size Groups during September 1974 to August 1975

[All values are in mm]

Size group	Breadth of shell	Width of opening	Height of spire
3- 3.9	2.5	1.5	2
4- 4.9	2.7	1.6	2.1
5- 5.9	3.7	2	3
6- 6.9	4.3	2.3	3.3
7- 7.9	4.8	2.5	3.9
8- 8.9	5.6	2.9	5.2
9- 9.9	6.3	3.1	5.7
10-10.9	6.9	3.5	6.3
11-11.9	7.4	3.7	6.8
12-12.9	7.7	4.1	7.2
13-13.9	8.1	4.6	7.8
14-14.9	8.8	5	8.5
15-15.9	9.3	5.8	9
16-16.9	10.3	6	9.4
17-17.9	10.6	6.1	9.7

Changes in shape of shell with growth—Changes in the shape of the shell of the snail as it grows in height were studied by taking the mean ratios of dimensions of the shell and by arranging them in different height groups as shown in Table 5.

Ratio of height to breadth: This ratio increases steadily from young animals to adult animals indicating that the shell grows in breadth steadily along with the growth in height, which is uniform throughout the growth period.

Ratio of height to width of opening: A steady increase in this ratio is seen from 3-6 mm size group to 9-12 mm size group. After 9-12 mm size group the ratio decreases slightly and is almost constant in the remaining 2 size groups. This indicates that up to 9-12 mm the growth in the shell height is more rapid compared to the growth of the opening (aperture). Afterwards the aperture gets thickened and so the width increases.

Ratio of height to height of spire: In this case a steady decrease is noticed from 3-6 mm size group to 12-15 mm size group. However, in case of adults this ratio is observed to increase. This indicates that after 12-15 mm size, the shell height increased because of the growth of the outer lip of the aperture of the body whorl, while the growth of the spire is negligible, where as the shells below 12-15 mm size it was vice versa.

Table 5—Variations in the Ratios Height/Breadth, Height/Width of the Opening and Height/Height of the Spire with the Growth of the Snail

Size group (mm)	Height/ breadth	Height/width of opening	Height/height of spire
3- 6	1.38	2.5	1.8
6- 9	1.5	2.9	1.77
9-12	1.5	3	1.66
12-15	1.57	2.83	1.65
15-18	1.64	2.82	1.78

Discussion

There is no indication of a clearcut seasonal variation in the growth rate of *C. clypeomorus*. It appears to be steady throughout the year unlike in earlier reports on other molluscs[8,18-23].

Comparison of the shell height and age relationship of *C. clypeomorus* with the closely related *Cerithium* species of Florida, shows that the members of the latter genus attain shell heights more than that of *Clypeomorus*, but the life span appears to be same in both the cases. *C. clypeomorus* attains a maximum shell height of 18 mm and survives for about 1 yr. It is an established fact that in tropical waters the animals are subjected to higher temperatures which results in increased initial growth, precocious maturity and shortening of life span of the organisms[24]. Ward[8] has attributed the smaller size of the limpets at Barbados to the intensive reproductive activity of the animals. Observations made while studying the breeding habits have shown that *C. clypeomorus* attains sexual maturity at a shell height of 11-12 mm and the breeding is continuous. Further from the sigmoid growth curve it is seen that the animals measuring 11-12 mm height are about 5 months old. Therefore, the small size and relatively short life span of *C. clypeomorus* may be due to the early attainment of maturity and nearly continuous reproductive activity of the animals on the Visakhapatnam coast.

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Coastal Currents Off Mangalore & the Possibility of Their Relationship with Pelagic Fish Catches in the Area

M P M REDDY, V HARIHARAN & N P KURIAN

College of Fisheries, University of Agricultural Sciences, Mangalore 575 002

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Coastal currents off Mangalore along the west coast of India have been measured for 2 yr using a specially fabricated float and drag system. The currents are directed towards north from October to February and towards south in April and May along this coast. March appears to be the transition period. The strength of the current varies from month to month. Northerly current seems to favour good catches of oil sardine and mackerel, and poor catches are associated with the starting of the southerly current. Magnitude of the current also appears to have some influence on the pelagic fish catch.

A clear knowledge of coastal currents along a coastline will be very useful in fishing operations. The coast near Mangalore on the west coast of India is noted for its pelagic fisheries of oil sardine and Indian mackerel. Detailed information on coastal currents in the region is not available except for the current observations carried out in connection with the location of the new harbour near Mangalore[1,2]. The present paper deals with the observations on coastal currents off Mangalore during 1976-1978. An attempt has been made in this study to relate the pelagic fish catches with the coastal currents off Mangalore.

Materials and Methods

A float and drag system specially fabricated and tested[3], was let out in the coastal waters near Mangalore and its movement was followed from the coast by 2 observers simultaneously by means of 2 theodolites. The coastal currents were computed later from the trajectory of the float. Measurements were made once a month off Bengre and Ullal from October 1976 to May 1977 and off Thannirbhavi and Someshwara from October 1977 to May 1978. To cover a greater length of the coastline, position of the theodolites was shifted from 1976-77 to 1977-78. The location of the 2 theodolites at Bengre, Ullal, Thannirbhavi and Someshwara beaches adjacent to Mangalore are shown in Fig. 1. The observations were always carried out on 2 consecutive days in each month at the 2 locations.

The accuracy of the triangulation method used in the present investigation depends on the resolving power of the theodolites, distance between the 2 theodolites and the shape of the coastline. The resolving power of the theodolites used in this study was quite sufficient to see the float-mast and flag up to 20 m depth. Distance between the 2 theodolites was reasonably large enough *c* 1 km to minimise the error. The coastline between the 2 theodolites was straight in all the 4 locations for easy and direct communication between the 2 observations.

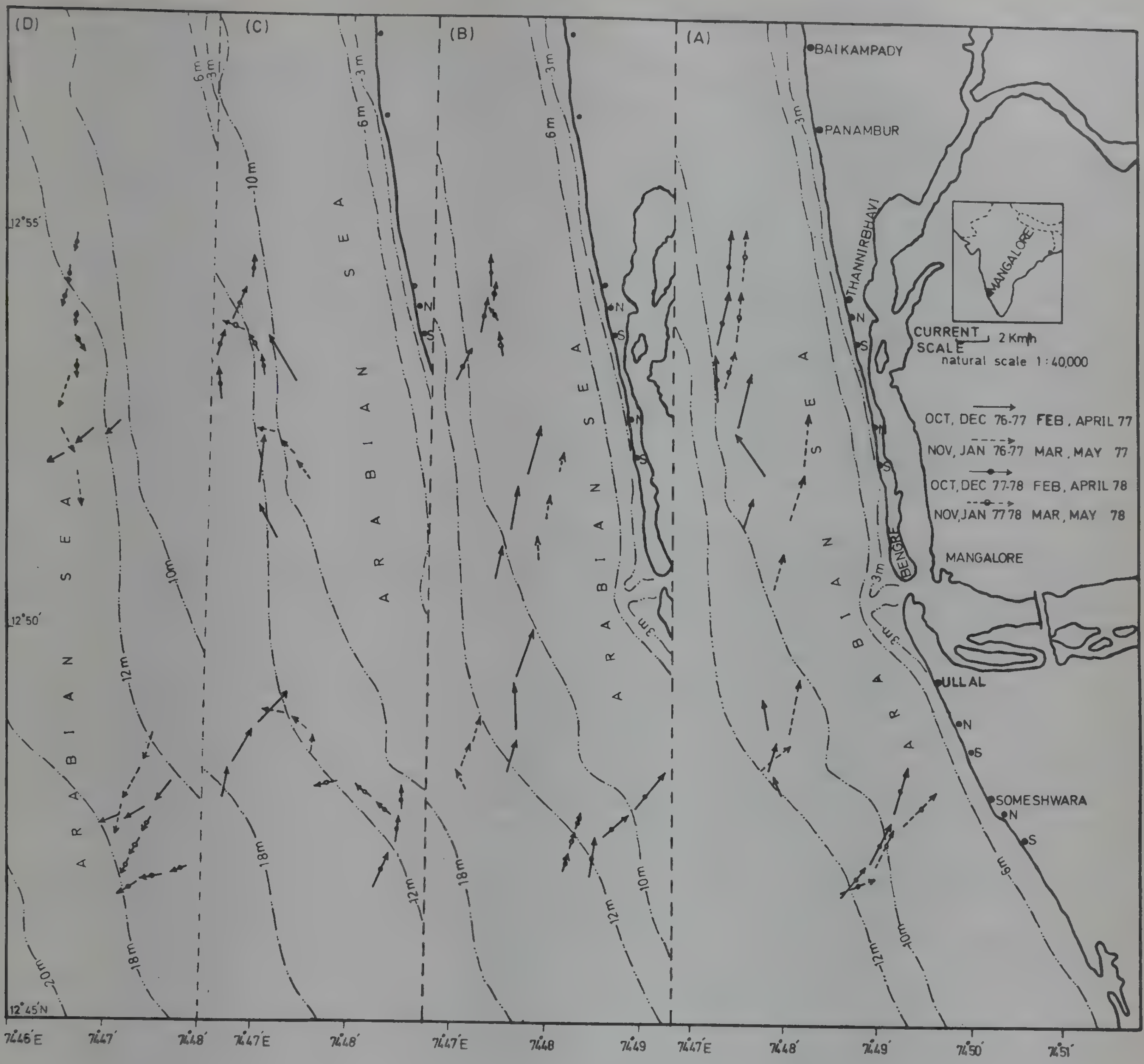
In order to find out the possible relationship between the coastal currents and pelagic fish catches, fish landing data for oil sardine and Indian mackerel were collected from CMFRI, Sub-station, Mangalore. The fish catch data from Ullal and Baikampady (north of Thannirbhavi) were added since the whole area between these 2 landing centres can be considered as a single unit as far as the fish catches are concerned.

Results and Discussion

The direction of current in different areas during different periods of study is shown in Fig. 1 and the magnitude of current (range in km/hr) is given in Table 1.

The monsoon circulation develops drift currents in the Arabian Sea off Mangalore. The observations for 2 yr reveal that the currents are towards north from October till February. The currents turn towards south in April and May. March appears to be the transition period as far as the direction of current is concerned. The intensity of current varies from month to month. In general, the magnitude of the current on both sides of Mangalore appear nearly same in any particular month though there are some variations in certain months.

However, there is a possibility of some discrepancy between the currents obtained during 1976-77 and 1977-78 due to sea level changes from 1st year to 2nd year. In view of this, time lapse of 1 yr between observations of 2 pairs of stations is specially chosen to know the differences in currents, if any, over a longer period. The effect of tide also may perhaps cause some


(D)
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BAIKAMPADY
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CURRENT SCALE 2 Km/h
natural scale 1 : 40,000
OCT, DEC 76-77 FEB, APRIL 77
NOV, JAN 76-77 MAR, MAY 77
OCT, DEC 77-78 FEB, APRIL 78
NOV, JAN 77 78 MAR, MAY 78
ARABIAN SEA
3m
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74°51′

Fig. 1—Currents off Mangalore during (A) October-November, (B) December-January, (C) February-March and (D) April-May

Table 1—Magnitude of Current (range in km/hr)

Location	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May
Bengre	2.0-3.6	2.0-3.2	1.8-2.8	1 -1.4	2.2-3	1 -1.2	1.2-1.4	1.7-2.1
Ullal	1.2-1.8	2.2-3.4	2 -3	1 -1.4	1.8-2.6	0.9-1.1	1.3-1.5	1.6-2
Thannirbhavi	2.8-3.6	2.4-3	2 -2.4	0.8-1.4	1.4-2.2	1 -1.3	1 -1.3	1 -1.3
Someshwara	2.4-3	2.2-2.8	2.2-3	0.6-0.8	1.4-2.2	0.9-1.1	1 -1.3	0.9-1.1

difference on the observations as these were taken on consecutive days on both sides. In spite of these limitations, this method of obtaining currents seems to be useful in getting an idea of the strength and direction of currents.

Possible relationship of coastal currents and pelagic fish catches (oil sardine and mackerel) in the Mangalore area—Geographic distribution of oil sardine in the Indian ocean extends from Arabia to Phillippines through Seychelles, India, Ceylon, Andamans and the

Malay Archipelago[4]. The Indian mackerel has been recorded in the Indian ocean from the Persian Gulf, along the coasts of Somalia, Seychelle Islands, India, Andaman and Nicober Islands, Ceylon and Burma. Thus, in general, the geographical distribution of both oil sardine and Indian mackerel coincides with the North Equatorial current region of the Indian ocean. Along the Indian coastline, oil sardine is confined largely to the west coast, though, during certain years, stray catches of the species are made along the coasts of Tamil Nadu and Andhra Pradesh along the east coast as well. Along the west coast large shoals of oil sardine occur from Quilon in the south to Ratnagiri in the north. Similarly, the main mackerel fishery along the Indian coastline, is confined to the west coast of India from Ratnagiri to Cape Comorin but sporadic shoals are seen along the coasts of Tamil Nadu, Andhra Pradesh and Orissa.

The surface current pattern of wind drift in the Arabian Sea as observed off Mangalore seems to influence the migration of oil sardine and mackerel shoals. During October to February the direction of current in this region is towards north. As the current from the southern boundary of the clockwise cell in the Bay of Bengal during this period joins with the North Equatorial current, there would be a concentrated westward flow south of Ceylon[5]. This strong current may take a northerly deviation from its general westward flow with which the oil sardine and mackerel shoals migrate along the west coast of India. Thus, this northerly drifts seem to be responsible for bringing such fishes into the Indian coastal waters especially along the west coast. With the onset of south-west monsoon, North Equatorial current is replaced by eastward flowing south-west monsoon current south of Ceylon. The coastal currents along the west coast of India as noticed from the currents off Mangalore during May are towards south. This may cause the oil sardine and mackerel to move away into the south-west monsoon current which flows to east.

Pelagic fish catch of oil sardine and Indian mackerel for Mangalore area for October 1976 to May 1978 (Table 2), mostly taken by fishing boats within 20 m depth, is high during October to December and February and relatively low during January and March. It is poor during April and May. Coastal currents in the area are generally towards north during October to February and towards south during April and May (Fig. 1). March appears to be the transition period for the currents and hence they are somewhat oriented towards west. The current speeds are high during October to December and February whereas in January they are relatively less. If wind generated currents are stronger, conditions would be more favourable for migration of the pelagic fish towards the coast[6]. This could be the reason for the relatively high catches during October to December and February and low catches during January though the current direction is towards north in all these months. During March, since the current is somewhat oriented towards west, the fish catch is relatively less at this time. The poor yield during April and May may be due to the southerly current at this period. The catches are high during October to December and February, moderate in January and March and poor from April to September. The pelagic fish shoals are good with the commencement of northerly current in October and are high till February with a moderate value during January probably due to the relatively low current speeds. They decreased in the transition period (March) at the end of the north-east monsoon season and became poor with the commencement of the southerly current in April. Thus, the pelagic fish of oil sardine and mackerel appear to be using northerly and southerly currents prevailing along the west coast of India for their migration.

Table 2—Total Monthly Landings of Pelagic Fish (Oil Sardine and Mackerel) Landed near Mangalore (Ullal and Baikampady) during October 1976 to May 1978*

Month	Pelagic fish landings (oil sardine + mackerel) kg	Month	Pelagic fish landings (oil sardine + mackerel) kg
1976 Oct.	136067	1977 Oct.	155674
Nov.	106507	Nov.	139110
Dec.	81393	Dec.	103137
1977 Jan.	30400	1978 Jan.	20159
Feb.	92013	Feb.	75000
March	33392	March	32829
April	4378	April	8195
May	4634	May	8084
June	—		
July	14020		
Aug.	11556		
Sept.	17344		

*Courtesy Central Marine Fisheries Research Institute, Sub-Station, Mangalore

In view of this possible relationship between the currents and the movement of pelagic fishes along the west coast of India, it is desirable to tag commercially important fishes like oil sardine and mackerel in the region of the current drifts together with the simultaneous measurement of coastal currents along the west coast and follow the movement of fish throughout the coast. Results of such studies would lead to a better understanding of the relation between currents and movement of pelagic fish which may ultimately help in forecasting these fisheries in advance.

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Oceanographic Studies Off Narara Bet, Gulf of Kutch

V C JOHN, P S SRIVASTAVA & A K MALHOTRA
Engineers India Limited, New Delhi 110001

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Oceanographic data have been collected *in situ* along the submarine pipeline route (lat. 22° 30′ 34″ N, long. 69° 42′ 04″ E to lat. 22° 28′ 06.07″ N, long. 69° 43′ 27.33″ E) off Narara Bet, Gulf of Kutch, from November 1977 to February 1978. Currents in this area are predominantly tidal with bimodal distribution. Maximum current speeds during spring tides are 0.97 m/sec towards 70° during flood, and 0.67 m/sec towards 250° during ebb. Maximum flood and ebb currents occur 2½ to 4 hr earlier and later to high water, respectively, at all locations. Correlations between tidal ranges at Sikka and tidal currents at locations 1 to 3 have been established (lat. and long. of locations 1 to 3 — location 1.22° 30′ 34″N, 69° 42′ 04″E, location 2:22° 30′ 06″N, 69° 42′ 24″E and location 3:22° 29′ 37′N, 69° 42′ 38″E). Calmest months suitable for offshore installations appear to be November to February. Current components perpendicular to the pipeline due to wind, wave, and tide are maximum at surface (1.25 to 1.4 m/sec). These decrease to 0 79 to 0.9 m/sec at mid-depth, and remain nearly the same at bottom. Maximum (27.5°C) and minimum (20.1°C) sea water temperatures are observed at location 4 (lat. 22° 29′ 13″N, long. 69° 42′ 52″E) during April and January, respectively. Diurnal variations of temperature at the surface and near the bottom are about 0.5°C, whereas, it is negligible at mid-depth. In general salinity distribution at all locations shows a slight increase with depth, while conductivity shows a slight decrease with depth. Maximum and minimum salinities are 36.9 and 35.0‰ respectively. Maximum and minimum conductivities of 55.9 and 49.9 mmho have been observed in November and February respectively. Chemical properties of seawater, viz. *p*H, dissolved oxygen, phosphate and sulphate, have also been discussed. In general, maximum suspended loads are observed at location 3, where the seabed consists of silt and silty clay Sea water in the area is mainly transparent (93.4 to 99.9%).

A single buoy mooring facility (SBM) to accommodate very large crude carries (VLCC) of about 2,70,000 DWT, has to be provided off Narara Bet for Indian Oil Corporation. These VLCCs will need a water depth of about 30 m which is available at a distance of about 5 km off Narara Bet in the Gulf of Kutch. This location has been chosen because the area is sheltered from severe wave activity of the Arabian Sea and also as it is nearer to the Middle East from where these VLCC's are expected to operate. A study[1,2] regarding the general tide and current pattern in the Gulf of Kutch has already been made. Oceanographic data along the submarine pipeline route from the shore point to off shore terminal for the period 26 January 1976 to 20 April 1976 have been collected[3]. This paper presents data on current, temperature, salinity and conductivity along the submarine pipeline route. Data have been analysed to evaluate currents for construction periods and also to establish the minimum expected temperature to decide the type of crude to be transported through the submarine pipeline. Data on sulphate, dissolved oxygen, nitrate and conductivity have also been collected to decide on the anticorrosive measures for submarine pipeline and single buoy mooring.

Description of Area

Bathymetry—The area shows 4 distinct morphological zones: (i) Inter tidal flat which dries up at low tide is about 2.2 km wide with a slope of 1:500. (ii) Inner slopping zone varies from 0 to about 16 m depth below chart datum with a slope of about 1:20. (iii) Intermediate undulatory zone which consists of undulating ridges and intervenning troughs, has water depths varying between 12 and 20 m. (iv) Outer uniformly sloping zone has uniform water depth varying from 20 to 30 m. In the first 1.2 km the slope is about 1:150 which changes to 1:400 towards offshore.

Meteorology—General meteorological data for the nearest location is available only for Jamnagar (lat. 22° 27′N, long. 70° 02′E) for the period 1931-1960.

Winds: Normal wind system in the area is basically seasonal with reversals of directions[2]. High wind speed, for a greater percentage of time, occurs during May to July. Predominant direction of these winds is between west to south west. November is the calmest month in the area with wind speeds exceeding 22 km/hr for about 8.3% of time. Wind speed rises to a peak in the afternoon and falls during night. Wind speed exceeding 44 km/hr can occur for a stretch of about 8 hr during July, while the average duration of such winds may be about 3 hr. Extreme winds at the SBM terminal site are expected during cyclonic period During the severe cyclone of October 1975, which passed through Jamnagar, the maximum recorded wind speed was 167 km/hr from easterly direction.

Air temperature: The hottest months in the area are May and June when the maximum temperature attains

44°C (approx.). Coldest (2°C) months are January and February.

Rainfall: Maximum rainfall occurs during July (220 mm). The annual rainfall is 490.3 mm. During July rainfall can be expected for about 9 days. There is no rainfall in the area from November to April.

Visibility: Visibility is better in the evening than in the morning. Poor visibilities of about 0-4 km occur for about 5 days during the monsoon months (May to September).

Hydrography—There is no major river discharging into the Gulf and the average annual rainfall in the area is < 50 cm, hence, a 2 layer flow as encountered in a normal esturaty is not expected in the area. A brief description of tides, waves and general currents is given below.

Tides: Tides in the area are of mixed type and are predominantly semi-diurnal with a large diurnal inequality. The tidal parameters in the area are mean high water spring (6.2 m) and neap (4.1 m) and mean low water neap (2.3 m) and spring (0.2 m).

Waves: Extreme waves are expected during cyclonic period. Maximum wind speed at the terminal site has been recorded during October 1975 cyclone, and wind data for the above cyclone have been used to hindcast the maximum probable wave height at the terminal site, using Brestchneider's[4] technique. Maximum wave height thus hindcast has been 9.5 m; the significant height and significant period being 5.1 m and 8.3 sec respectively. Predominant direction of approach of these waves is between east and northeast.

Currents: Current directions off Narara Bet are bimodal, with predominant directions and peak speeds nearly parallel to the bottom contour. Predominant and maximum surface currents recorded are 0.2 and 0.9 m/sec respectively. Two predominant directions of recording are 78°N ± 10° during flood and 213° ± 10° during ebb period. These 2 predominant directions are separated by 135° rather than 180°. For about 5% of time, speed remains < 0.05 m/sec which represents slack period between flood and ebb tides. Current speeds during spring exceeded 0.5 m/sec for 37% of time.

Bottom currents also reveal bimodal current directions. Predominant directions are 110° ± 10° during flood and 169° ± 10° during ebb period. These 2 predominant directions are separated by 135° rather than 180°. Predominant bottom flood current directions differed from the surface flood current directions by about 32°; with the bottom current turned more onshore. Ebb currents instead of following the directions 290° ± 10°, as expected, flow towards 169° ± 10°. Bottom currents are normally 70% of the surface currents. For about 5% of time speed remains < 0.05 m/sec which represents slack period between flood and ebb tides. Current speeds during spring exceed 0.5 m/sec for 37% of time.

Materials and Methods

Marker buoys which can withstand the drag forces, when a fishing boat is tied to it, have been designed and fabricated. Four such buoys were installed at locations 1 to 4 with the help of two shore theodolite stations. Communication between the theodolite stations and the boat was maintained by wireless sets. A local fishing boat about 11 m long was modified and fitted with a suitable *A* frame for the lowering and lifting of oceanographic equipment.

Aanderaa Model RCM4 capable of recording current speed and direction, conductivity and temperature up to a depth of 2000 m, was used to obtain *in situ* current data.

Nansen water bottles fitted with protected reversing thermometers were used to collect water samples for estimation of *p*H. salinity, dissolved oxygen, sulphate, phosphate, suspended load and transparency.

Various data were collected for about 2 to 3 days a week at locations 1 to 4 for the entire period of survey.

Analysis of data—Data for different depths and locations have been analysed and time series plots of tides, currents, temperature, conductivity and salinity have been prepared [These data are available with the authors for reference]. Densities of sea water have been computed based on salinity and temperature data. Monthwise maximum and minimum temperature, conductivity, salinity and *p*H for each location are presented in Table 1. Maximum flood and ebb currents, recorded for different locations and depths have been given in Table 2. Since the data on *p*H, dissolved oxygen, phosphate, sulphate, suspended load and turbidity are limited, maximum and minimum of these parameters for the entire period of survey have been prepared for different locations (Table 3).

Calmest months in this area are November to Februa y[2] Hence these months are the best for offshore installations. During this period normal maximum wind speeds expected in the area are 38 km/hr from 40°. Significant wave height and period during this season are 1.25 m and 6 sec from 300°. Installation currents due to wind[5], wave[6] and tide, perpendicular to the pipeline, have been computed (Table 4).

Results and Discussions

Currents—Current at any place can be due to one or a combination of the factors, viz. tide, wind, wave and density variations. Maximum sustained wind speed recorded is 27 km/hr from north to northeast. The wind driven current for this wind speed can be about 0.2 m/sec flowing towards south to south west. These

Table 1—Maximum and Minimum Temperatures, Conductivities, Salinities and Densities Recorded Off Narara Bet [Feb. to April 1976 and Nov. 1977 to Feb. 78]

Month	Temp. (°C)		Conductivity (mmho)		Salinity (‰)		pH*	
	Max.	Min.	Max.	Min	Max.	Min.	Max.	Min.
			Location 1					
Nov.	27	26.6	55.7	55.2	—	—	8.2	8
Dec.	26.2	24.5	54.9	53.4	35.4	35	8.1	8
Jan.	23.3	21.2	51.7	50.5	36.9	35.5	8.3	7.9
Feb.	21.5	20.9	50.5	49.9	36.5	36	—	—
March	26.5	22.8	—	—	36	36.6	—	—
April	26.9	24.4	—	—	36.8	36.1	—	—
			Location 2					
Nov.	27	26.8	55.6	55.3	—	—	8.1	8
Dec.	26	24.4	54.8	54	35.4	35.2	8.2	8.1
Jan.	22.9	21.5	51.7	50.4	36.8	35.6	8.2	7.6
Feb.	21.5	20.9	50.6	49.9	36.6	35.8	—	—
March	26.8	23.0	—	—	36.8	36.1	—	—
April	27	24.5	—	—	36.8	36.2	—	—
			Location 3					
Nov.	27.2	26	55.7	55.3	35.4	35.2	8.1	8
Dec.	26.2	23.3	55	54.2	35.4	35.1	8.2	8.1
Jan.	23.3	21.4	52.1	50.2	36.6	35.6	8.4	7.5
Feb.	21.3	20.8	50.5	50	36.6	36.1	—	—
March	26.4	22.2	—	—	36.8	36.1	—	—
April	27.3	24.5	—	—	36.9	36.3	—	—
			Location 4					
Nov.	27.1	26.4	55.9	55.1	35.4	35.2	8.1	8
Dec.	26.2	23.4	54.9	53.1	35.3	35	8.1	8.1
Jan.	23.4	20.1	52.3	50.2	36.5	35.6	8.4	7.2
Feb.	21.3	21	50.4	50.2	36.7	36	—	—
March	26.5	23.4	—	—	36.9	36.1	—	—
April	27.5	24.5	—	—	36.9	36.3	—	—

*pH values for November and December are based on limited data

wind driven currents are superimposed over tidal currents and hence are likely to increase the ebb velocities and reduce the flood velocities.

Maximum wave height observed (visual observations) during the recording period is around 0.7 m occurring for a very short period. The wave induced currents due to these waves assumed to be negligible.

Because of the strong tidal currents, large scale mixing takes place in this area and hence a nearly uniform density distribution is expected. There is no river discharging into the area and the annual rainfall is only 49 cm. Therefore density currents in the area are negligible.

Because of large tidal ranges the predominant currents in the area are of tidal origin (vary from 2.6 to 6.2 m). A detailed description of currents at various locations is presented below:

Location 1: Currents at this location are mainly tidal with a bimodal distribution. Predominant flood and ebb directions are 75° ± 5 and 250° ± 5 respectively. The current direction is reversed by 180° within about 15 min during the slack period. Maximum flood current (0.97 m/sec towards 70°) has been observed near bottom on 10 December 1977. The flood tidal range recorded during this period is 5.9 m. Ebb currents are comparatively weaker and the maximum has been 0.67 m/sec towards 250°, corresponding ebb tidal range are in general less than flood tidal ranges in this area and hence ebb currents are generally weaker than flood currents.

There is no appreciable reduction in current speed from surface to 2 m above bottom. However in exceptional cases variations up to 14% has been observed. Flood currents are generally 20 to 30%

Table 2—Maximum Flood and Ebb Currents Recorded at Various Locations
[24.11.77 to 15.2.78]

Depth	Maximum Currents					
	Flood			Ebb		
	Date & time	Speed m/sec	Dir. (°N)	Date & time	Speed m/sec	Dir. (°N)
Location 1						
	10-12-77	0.83	75	26-1-78	0.67	250
S	2230			1812		
Md	2206	0.89	75	1606	0.66	250
B	2242	0.97	70	1800	0.62	245
Location 2						
	8-2-78			26-1-78		
S	1136	0.74	70	1812	0.67	250
Md	1145	0.73	70	1748	0.66	250
B	1115	0.67	65	1800	0.62	245
Location 3						
	11-2-78			24-11-77		
S	1124	0.66	65°	1512	0.65	250
Md	1236	0.66	65°	1818	0.62	250
B	1145	0.62	60°	1525	0.48	245
Location 4						
	28-11-77					
S	1212	0.45	65	—	—	—
B	1112	0.42	60	—	—	—

S = Surface; Md = mid depth; B = bottom

stronger than ebb currents. Maximum flood and ebb speeds occur about 3 hr earlier and later to high water respectively.

Current data collected during the period 13 July to 15 August 1973 at a depth of about 7 m below C.D. shows that the maximum flood is 0.76 m/sec towards 78° ± 10°. Data collected in the present study (Table 2) show higher values.

Similarly the maximum ebb current recorded during the above period has been 0.65 m/sec towards 230°. This speed value is comparable to the present measurements whereas the direction differs by about 20°. The probable reason for this discrepancy is not understood.

Bottom currents at all the locations show a tendency to turn anticlockwise by about 5° compared to surface currents. This could be attributed to the orientation of the bottom contours which are about 330°. Current speeds at all levels reduce gradually from location 1 to 4.

Location 2: As in the case of location 1, currents in this location are also mainly tidal and bimodal in direction with quick reversal of direction during slack period.

Maximum surface flood current recorded is 0.74 m/sec flowing towards 70°, whereas the maximum ebb current recorded is 0.67 m/sec towards 250°. Unlike in the case of location 1, the maximum current speed has been recorded near the surface and is about 10% stronger than the near-bottom current.

Maximum flood and ebb currents occur about $2\frac{1}{2}$ to 3 hr earlier or later to high water respectively. The flood and ebb directions are steady, and change by around 180° during slack water within about $\frac{1}{2}$ hr.

Location 3: Maximum flood current recorded at the surface is 0.66 m/sec towards 65° and ebb 0.65 m/sec towards 250°. Bottom currents are about 6% weaker than the surface current. The currents turn in the anticlockwise direction while approaching the shore. The change in direction from location 1 to 3 is around 10° and this can be due to the bottom features as the orientation of the bottom contours change.

Maximum flood and ebb currents occur 3 to 4 hr earlier or later to high water respectively.

Location 4: Detailed current measurements could not be carried out at this location because of the dredging activity near the reef edge. The maximum flood current recorded at this location is 0.42 m/sec towards 65°.

Normal currents during installation: Maximum wind driven currents expected during installation are, 0.26 m/sec towards 223° ± 5° at surface, 0.15 m/sec towards 147° ± 5° at mid-depth and 0.13 m/sec towards 72° ± 5° at bottom. Near surface maximum tidal currents reduce from 0.83 m/sec at location 1 to 0.66 m/sec at location 3. Wave induced currents at surface are equally strong as the tidal currents (0.63 to 0.67 m/sec). However these currents reduce exponentially with depth and are negligible near the bottom (0.06 to 0.21 m/sec). Current components perpendicular to the pipeline are maximum at surface (1.25 to 1.40 m/sec). There is a sudden reduction in current speeds at mid depth and the speed remain nearly the same at the bottom (0.79 to 0.90 m/sec). Currents in the breaker zone will be comparatively higher than at all these locations.

Sea water temperature—Important factors which will affect the temperature variations along the pipeline route in the Gulf of Kutch are solar radiation, wind, tides and tidal currents, and land boundary affect.

Solar radiation and wind are important in causing seasonal temperature changes in the area. Because solar radiations per unit area decrease from November onwards, and during winter months wind speeds are comparatively lower, to add significantly to the advected heat in the area, hence the sea water temperatures on the average decrease from November to February (Table 1). From March onwards the temperature again starts increasing reaching ma-

Table 3 — Maximum and Minimum Dissolved Oxygen, Phosphate, Sulphate, Suspended Load and Transparency Recorded Off Narara Bet

[January to April 1976 and November to December 1977]

Month	Suspended load (ppm)		Transparency, %		Dissolved oxygen (ml/litre)		Phosphate (mg/litre)		Sulphate (mg/litre)	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
					Location 1					
Jan.	56	Tr*	99.9	96.8	—	—	—	—	—	—
Feb.	32	Tr	99.9	94	—	—	—	—	—	—
March	39	4	99.8	95	—	—	—	—	—	—
April	44	4	99.8	97	6.4	2.7	—	—	—	—
Nov.	—	—	—	—	—	—	0.01	0.01	2642	2546
Dec.	—	—	—	—	—	—	0.01	0.01	—	—
					Location 2					
Jan.	116	Tr	99.9	95.8	—	—	—	—	—	—
Feb.	29	Tr	99.9	93.4	—	—	—	—	—	—
March	32	2	99.8	95	—	—	—	—	—	—
April	31	Tr	99.8	97	6.1	2.7	—	—	—	—
Nov.	—	—	—	—	—	—	0.01	0.01	2642	2593
Dec.	—	—	—	—	—	—	0.01	0.01	—	—
					Location 3					
Jan.	70	Tr	98.8	96	—	—	—	—	—	—
Feb.	48	Tr	96	94.2	—	—	—	—	—	—
March	38	Tr	99.7	95.4	—	—	—	—	—	—
April	27	2	99.8	97	6	3.2	—	—	—	—
Nov.	—	—	—	—	—	—	0.01	0.01	2642	2593
Dec.	—	—	—	—	—	—	0.01	0.005	2546	2546
					Location 4					
Jan.	61	Tr	99.9	95.4	—	—	—	—	—	—
Feb.	31	Tr	99.2	95	—	—	—	—	—	—
March	34	2	99.4	95.2	—	—	—	—	—	—
April	36	5	99.8	97	6	2.8	—	—	—	—
Nov.	—	—	—	—	—	—	0.01	0.01	2642	2593
Dec.	—	—	—	—	—	—	0.01	0.005	—	—

*Tr = Traces

Table 4—Normal Currents Expected along Pipeline Route during Installation

Depth	Wind driven current		Tidal current		Wave induced current		Component perpendicular to pipeline			
	Speed (m/sec)	Dir. (°N)	Speed (m/sec)	Dir. (°N)	Speed (m/sec)	Dir. (°N)	Wind	Tide	Wave	Total
					Location 1					
S	0.25	220	0.83	75	0.63	120	0.24	0.18	0.35	1.40
Md	0.15	145	0.83	75	0.13	120	0.02	0.81	0.07	0.90
B	0.13	70	0.8	70	0.06	120	0.13	0.79	0.03	0.95
					Location 2					
S	0.26	223	0.74	70	0.64	121	0.24	0.73	0.35	1.32
Md	0.15	147	0.73	70	0.18	121	0.02	0.72	0.10	0.84
B	0.13	72	0.67	65	0.11	121	0.13	0.67	0.06	0.86
					Location 3					
S	0.26	227	0.66	65	0.67	124	0.25	0.66	0.34	1.25
Md	0.15	151	0.66	65	0.28	124	0.01	0.66	0.12	0.79
B	0.13	77	0.62	60	0.21	124	0.13	0.62	0.11	0.86

S = Surface; Md = mid depth; B = bottom

ximum (27.5°C at surface) in April and minimum (20.1°C at bottom) in January, at location 4. It may be mentioned that water trapped in large depressions over the coral reef get heated and cooled more than the surrounding waters. These high and low temperatures might have been recorded in one such pool over the coral reef. Tides and tidal currents bring about a thorough mixing in the area, hence for any day practically constant temperature occurs from the surface to bottom. Since there is no significant variation of temperature with depth, spatial variation of temperature along the pipeline route are discussed below:

Surface temperature: Sea water temperatures in the areas nearer to the tidal flat show greater variations, because corals get heated up as well as cooled, quicker than the deeper parts of the Gulf. The water in this area are more turbid, contain more microorganisms and consequently absorb more radiation[4]. The minimum surface water temperature (21.1°C) has been recorded at location 4 during mid-February.

Sea surface temperatures show diurnal variation of about 0.5°C. Maximum (27.3°C) temperatures are recorded between 14.00 and 15.00 hr and minimum (21.1°C) between 04.00 and 05.00 hrs. Minimum air temperature is normally obtained in the early morning hours. Temperature data collected earlier[6] show that sea water temperatures are lowest during February (21.8°C) and start increasing from March onwards.

The only other long-term sea water temperature data, available for the Gulf of Kutch area, are from the Kandla creek[7] (about 3.5 km inside creek; lat. 23°01′N and long. 70°13′E).

Water temperatures are higher during June and July (28° and 30°C). Lower water temperatures occur during January and February (18.5°-22°C).

Mid-depth temperatures: Mid-depth temperatures show a decrease of about 5.5°C from last week of November 1977 to mid-February 1978. Minimum mid-depth sea water temperatures remain nearly (variation $<$ 0.3°C) constant from location 1 to 3. Maximum and minimum recorded mid-depth temperatures are 27.1 and 21.1°C respectively. Diurnal variation of temperatures at mid-depth is comparatively less prominant.

Near-bottom temperatures: Maximum recorded near bottom temperatures show a decrease of about 5.5°C from the last week of November to mid-February 1978. Minimum recorded near-bottom temperatures decreases by about 1°C from location 1 to location 4. The probable reason for this is since corals get cooled more than water, during winter nights. Water serves as a reservoir of heat hence its temperature does not vary much during its contact with surrounding air. Diurnal variations in sea bottom temperatures are about 0.5°C. Maximum and minimum recorded bottom temperatures are 27.1° and 20.1°C respectively.

Salinity and electrical conductivity—Because of the large scale mixing and lack of fresh water discharge a nearly uniform salinity and conductivity distributions are expected in the area. However decrease of temperature with depth has also been observed in the area. In general, the salinity distribution at all locations shows a slight increase with depth whereas the conductivity shows a slight decrease with depth. This could be due to the slight decrease of temperature with depth.

Lowest salinity at all the locations has been observed in December (35.0‰). Higher salinities (36.8 to 36.9‰) have been observed in March and April at locations 2 to 4, when higher seawater temperature have also been observed. This could be due to high evaporation during these months.

Diurnal variation of salinity shows maximum of 0.28‰ and minimum of 0.07‰. A gradual increase in the diurnal variation with depth has also been observed.

Gradual reduction in the conductivity has been observed from November to February at all locations. Maximum and minimum conductivities are 55.9 mmho in November and 49.9 mmho in February respectively. Maximum and minimum diurnal variations observed are 0.72 and 0.14 mmho, respectively.

Chemical properties—*p*H data are available only for November to January 1976. Maximum and minimum *p*H recorded are 8.4 and 7.2 respectively. A large variation of *p*H (7.2 to 8.4) has been observed in January. Dissolved oxygen data are available only for April 1976 and range from 2.7 to 6.4 ml/litre.

Phosphate content in the area (November to December 1976) are present only in traces and ranges from 0.005 to 0.001 mg/litre. Sulphate content estimated during the same period show in large quantities and ranges from 2546 to 2642 mg/litre.

Suspended load and transparency—Sediments along the pipeline route from location 1 to 3 change from coarse sand to silty clay. At location 4, coral growth has been observed. Since the bottom currents in the area are very strong, these sediments may be put into suspension and carried by the prevailing currents. An unusual maximum suspended load of 116 ppm has been observed at location 2. In general, maximum suspended load is observed at location 3, where the seabed consists of silt and silty clay. The seawater in the area is mainly transparent (93.4 to 99.9%).

Acknowledgement

The authors are grateful to their colleagues Mr S Basu for his valuable field work and Mr K C Bhatia for preparation of drawings. Data used in this paper have been collected by Engineers India Limited for its client Indian Oil Corporation, to whom they are obliged.

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Studies on Organic Carbon, Nitrogen & Phosphorus in Sediments of the Cochin Backwater

V N SANKARANARAYANAN & S U PANAMPUNNAYIL

National Institute of Oceanography
Regional Centre, Cochin 682 018

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Distributions, seasonal changes and ratios of organic carbon, total phosphorus and total nitrogen have been studied in sediments collected from 4 stations in Cochin backwater. The observed high organic carbon contents up to 3.84% in the sediments may be due to river discharge bringing in a large amount of water humus and also to high organic production of the overlying water. Total phosphorus distributions also show higher concentrations (0.9 - 2.4 mg/g), which may be attributed to the influence of domestic waste. Nitrogen/phosphorus ratios indicate that the major portion of phosphorus in the sediments is of abiogenic origin. Correlations between organic carbon and total phosphorus are also discussed.

Cochin backwater forms the northern extension of the Vembanad Lake along the Kerala coast. Comprehensive studies of the sediments and their mineralogy and chemistry have been made[1-3]. However, no information is available on the organic nitrogen and carbon/nitrogen (C:N) ratio of the sediments, which forms a useful tool in interpreting the data on organic matter and assessing the extent of nutrient regeneration in estuarine sediments. In the present paper data on the seasonal changes in the organic carbon, total nitrogen, total phosphorus and their ratios in the sediments collected in the backwater are given.

Materials and Methods

Sediment samples were collected at monthly intervals from 4 stations (Fig. 1) for the year 1975-76, using a van Veen grab. In the laboratory the samples were dried in a hot air oven around 70°C. Organic carbon was determined by the direct method of El Wakeel and Riley[4]. For the estimation of total nitrogen, microkjeldahl technique as described by Barnes[5] was followed. For determination of total phosphorus the sample was digested according to Rochford[6] and the orthophosphate estimated by the single solution method of Murphy and Riley[7]. The data are compared with published information and presented in Table 1.

Results and Discussion

Organic matter—Monthly variations in the organic carbon at different stations are presented in Fig. 2. In general, there is an increase in organic carbon during the southwest monsoon season (June-September) at all stations. Organic carbon values vary between 7.4 and 38.4 mg/g of dry mud (av. 16.2). Carbon values compare well with those reported by Murty and Veerayya[1]. Bhosle *et al.*[8] have reported organic carbon values for the shelf and slope regions of Cochin as 10.6 and 60 mg/g respectively. Data collected on board *RV Meteor*[9] show that the carbon values vary between 2 and 69.0 mg/g for the upper 2 cm of the sediments from the shelf region of Cochin. Cochin backwater is subjected to wide range of hydrographic conditions[10],

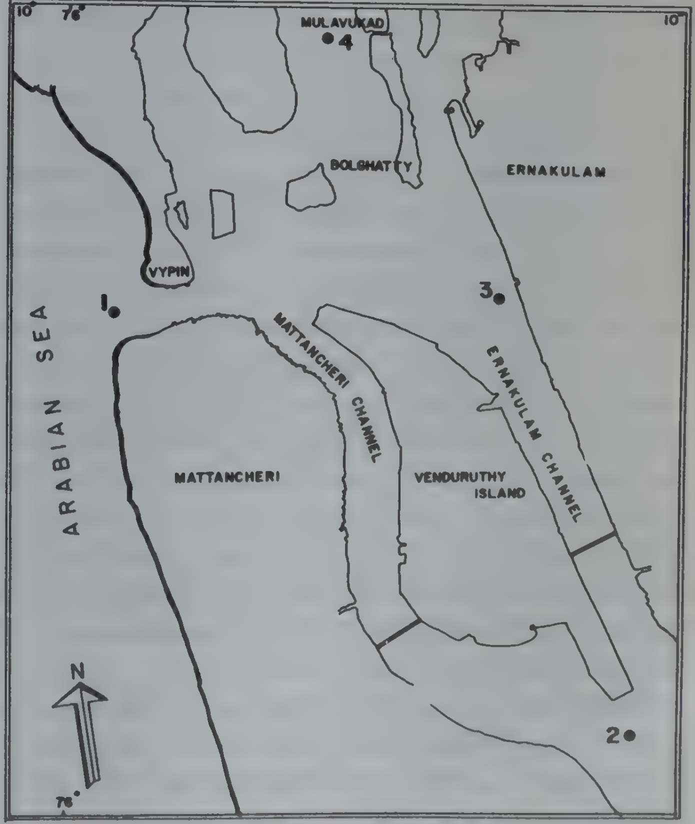

Fig. 1—Station location map

Table 1 — Comparison of Present Data with Reported Data for Sediments from Different Areas

[Number in parenthesis indicates reference]

Ranges observed in the present study, mg/g	Values reported mg/g	Remarks
	Organic carbon	
7.4 to 38.4; av. 16.2	2 to 69 (9)	For shelf and slope sediments in the upper 2 cm off Cochin in the Arabian Sea
	1.9 and 40.5; av. 14.2 (19)	For sediments of Lake Manzalah, Egypt
	Total phosphorus	
0.9 to 2.4	0.69 to 1.2 (18)	For sediments of Santa Monica basin
	0.16 to 1.03 (19)	For sediments of lake Manzalah, Egypt
	0.04 to 1.68 (2)	For muds of Vembanad Lake
	1.3 to 1.9 (13)	For detritus of Cochin backwaters
	1 (6)	For sediments in the Australian estuaries
	Total nitrogen	
0.9 and 5.7; av. 3.2	0.4 to 2(14)	In sediments of estuaries and lagoons in USA

with large freshwater runoff during June-September, when the chlorinity values go below 1‰. Qasim *et al.*[11] have reported the planktonic production of the backwater to be about 195 $gC/m^2/yr$ and the zooplankton grazers leave a considerable surplus of unconsumed basic food, which sinks to the bottom and becomes part of the sediment. They have also observed high values of primary production from April to August, and low values from September to March. Organic matter in the sediment in the estuary is mainly due to plant and animal matter brought in from land through runoff and deposited from the overlying water. It may be due also to plant and animal matter within the area and from the adjacent ecosystem. Associated with the fresh water runoff the silt in colloidal suspension containing large quantities of soil humates is brought into the estuary and the humic substance precipitates and settles in this region. Therefore, the seasonal variation in the organic carbon content in the sediments may be related to the plankton activity in the overlying water, the humic material brought in from land and also to the oxidation of organic matter by organisms living on the bottom.

Total phosphorus—Knowledge on the phosphorus concentrations in the mud is important, especially in shallow water systems, where mud acts as a reservoir of phosphorus in various forms and is regenerated into the overlying water under suitable conditions.

Monthly variations in the total phosphorus content in the mud are shown in Fig. 2. Total phosphorus content ranges between 0.9 and 2.4 mg/g (av. 1.5). In general, the values are found to be lower during the months June-September, followed by an increase in the following months. Lower values observed during the monsoon months are believed to be due to the leaching of the phosphorus, both the interstitial and adsorbed forms, from the mud to the overlying water. During monsoon months the freshwater flow dominates the system and during the high tide the saline water enters the estuary in the form of a tongue[12] and the intense water circulation during this season might be helping the release of more phosphates from the mud to the overlying water. Murty and Veerayya[2] have reported phosphorus concentrations in the muds collected from the Vembanad Lake during November/December between 0.04 and 1.68 mg/g (av. 0.42). The variability has been explained to be due to the variability in the texture of the sediments. They have also observed a decrease in the phosphorus content from the estuarine mouth to the freshwater zone.

Qasim and Sankaranarayanan[13] have reported the total phosphorus variation in the detritus of the Cochin backwater between 1.3 and 1.9 mg/g. The higher total phosphorus content observed during the present investigation in the sediments of the Cochin backwater may be due to the fact that the sampling zone is restricted to the estuarine part of the lake and also due to the effect of the domestic waste which is emptied in the region through canals.

Total nitrogen—Seasonal variation in the nitrogen content at different stations are given in Fig. 2. The values vary between 0.9 and 5.7 mg/g (av. 3.2). Seasonal variation of nitrogen does not follow any definite pattern. The values are slightly higher and the distribution is more or less uniform at station 1, in the marine zone than at other stations. Since hydrographic changes at this station are minimum the organic production in the overlying waters will be more uniform and there may be relatively higher accumulation of organic materials in the sediments from the overlying waters.

Carbon/nitrogen ratio—C/N ratio (by weight) in the backwater sediments varies between 2.5 and 16.9 (av. 6.4). Trask[14] has made analyses of organic carbon and nitrogen in sediments of estuaries, lagoons and oceans throughout the world and reported C/N ratio between 8 and 12. Carbon, nitrogen values estimated from sediment samples collected from the west coast of India during the cruises of *RV Meteor*[9] have shown a variation between 1 and 8. High C/N ratio (2.48-37.5) obtained by Bhosle *et al.*[8], for the shelf sediments of the Arabian Sea has been attributed to the degradation of complex protein. Qasim and Sankaranarayanan[13]

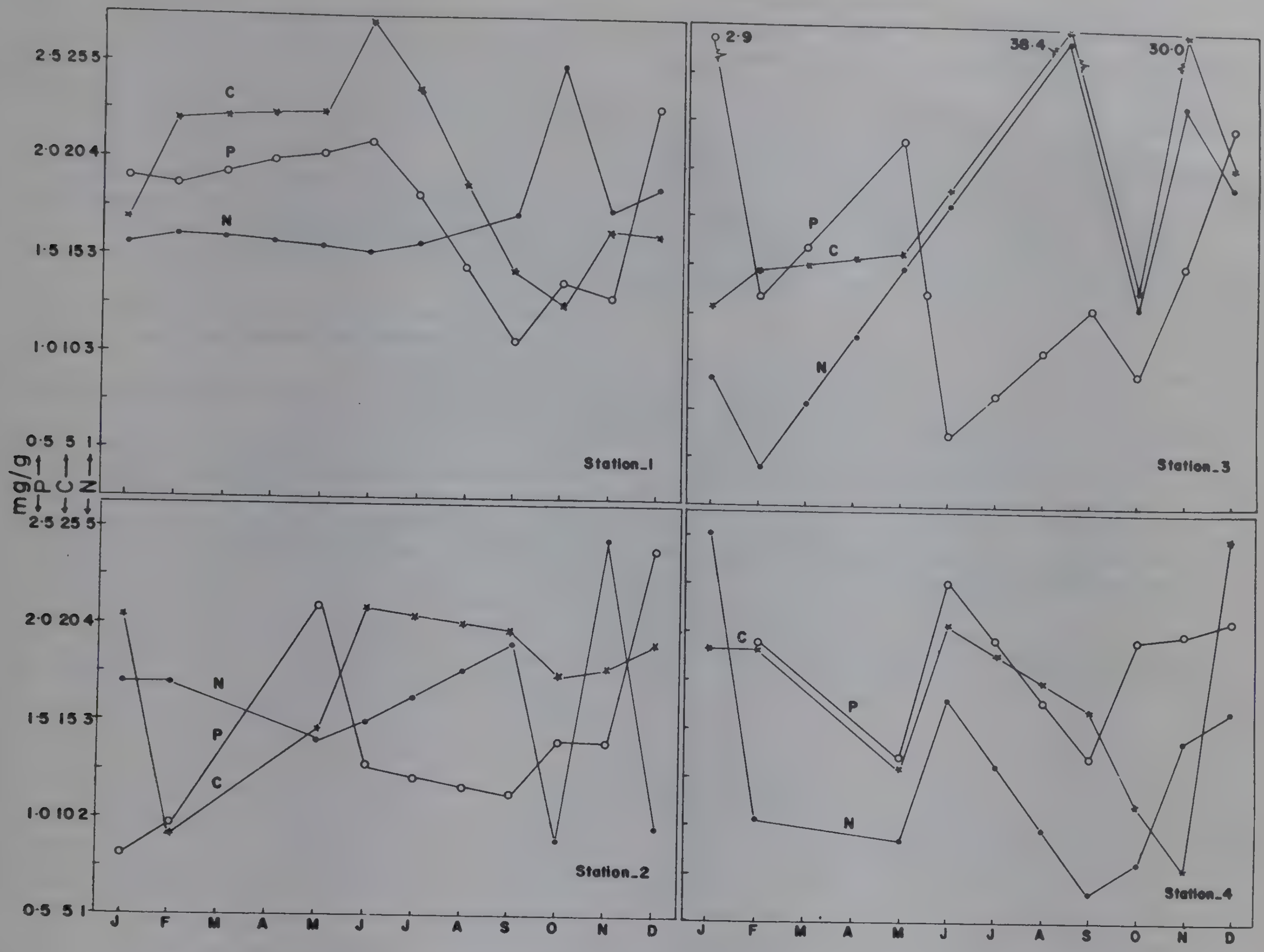

Fig. 2—Distribution of total phosphorus(P), total nitrogen(N) and organic carbon(C) at stations 1 to 4

have reported a C/N ratio between 5 and 10.5 with an average of 7.6 for the detritus of the Cochin backwater. Seasonal variation in the C/N ratio of the sediments of the Cochin backwater may be attributed to the changes in the physico-chemical characteristics caused by the freshwater discharge bringing in lot of organic matter, considerably high in humic materials, from land during the monsoon months and also to the more stable conditions during the premonsoon season, which are favourable for a good plankton population. Provasoli[15] suggested that sea water containing humic material of freshwater origin has a high C/N ratio, nearer to 10:1, which is the ratio in "Water humus".

Carbon/phosphorus ratio—C/P ratio varies between 2.25:1 and 27.41 (av. 10.67:1). For the detritus in the Cochin backwater a C:P of 22.61 to 60.4:1 an average of 41:1 has been reported by Qasim and Sankaranarayanan[13]. Qasim and Sankaranarayanan[13] have made a comparative study of the various chemical constituents in the detritus and in the sediments and concluded that the uppermost layer of the sediment is mostly of settled detritus. Lower C:P observed presently indicates the increase in the phosphorus content in the sediments, probably due to the effect of domestic sewage.

Nitrogen/phosphorus ratio—The weight ratios of total nitrogen to total phosphorus in the sediments vary between 1.2 and 4.07 (av. 1.51). This is lower than that of plankton. Grasshoff[16] has reported N:P in plankton as 13.3:1 and Sen Gupta *et al.*[17], have reported N:P for natural plankton as 13.8:1 and for culture plankton as 18.2:1. Rittenberg *et al.*[18] have reported relatively low N:P values for the sediments of Catalina, Santa Barbara and Santa Monica basins as 5.8:1, 3.3:1 and 1.4:1 respectively. The low N:P observed in the Cochin backwater indicates that the major portion of the phosphorus in the sediments is of abiogenic origin.

The present study indicates that, apart from hydrographic changes, humic material brought down by river discharge plays an important role in the cycle of organic matter in sediments in Cochin backwater. It is also clear from the organic carbon content as well as the ratios with other constituents like nitrogen and phosphorus that the degradation of organic matter is quite rapid. Low N:P and C:P ratios indicate significant contribution of phosphorus by sewage effluents and other sources in the environment.

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Studies on Pollution Ecology of Foraminifera of the Trivandrum Coast

K KAMESWARA RAO & T S SATYANARAYANA RAO

National Institute of Oceanography, Regional Centre
Cochin 682018

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Analysis of sediment samples collected from the beach sand and from 5, 10 and 20 m of water depths along 3 traverses off Thumba, Trivandrum Titanium Plant (T.T.P.) and Sankhamugham revealed the occurrence of 85 species of Foraminifera belonging to 42 genera under 26 families. Based on taxonomic assemblages, 3 faunal groupings were recognized, viz. beach fauna at 0-1 m, nearshore fauna at 1-5 m and offshore fauna at 5-20 m depth. Total foraminiferal population sizes were higher in February and March than in December. In general, it was observed that the stations were independent of each other with respect to seasonal variations of foraminiferal abundance. Solution effect on the tests of Foraminifera was observed at the outfall area as well as on the polluted parts of the beach. The species diversity was relatively low at the T.T.P. site when compared to stations along Thumba and Sankhamugham.

Significant contributions to the taxonomy of benthic Foraminifera of the continental shelf of south-west coast of India have been made[1-3]. The present work forms part of the sponsored project "Oceanographic survey for effluent disposal and submarine pipeline route for the Travancore Titanium Products Ltd, Trivandrum" conducted by NIO during December 1976 to April 1977. The principal objectives of this study are: (i) to investigate distribution and abundance of foraminiferal species; (ii) to study monthly variations of total and living populations of Foraminifera; (iii) to ascertain relationship between foraminiferal assemblages and marine pollution; and (iv) to know the effects of industrial effluents on Foraminifera.

Methods

Monthly collections of sediment samples were made from water depths of 5, 10 and 20 m along the 3 traverses at Thumba, T.T.P. (Trivandrum Titanium Plant) and Sankhamugham (Fig. 1) using Van-veen grab. Samples were washed on a 200-mesh sieve (0.063 mm mesh size) for counting and calculation of percentage occurrence of individual species of Foraminifera based on counts of 300 specimens. Also, sand samples (0-1 m) collected from the beaches were examined for Foraminifera. Live specimens were stained before sorting with rose bengal. In order to study the corrosive effect on the specimens of Foraminifera, obtained at the polluted sites, they were scanned by an electron microscope [Cambridge Stereoscan Model S4-10].

Hydrography

Both surface and littoral currents along the Trivandrum coast were studied in order to trace the dispersion trends of the effluents[4]. Coastal surface currents were weak and showed southward movement during February to April 1977. From January to March 1977, the littoral currents had a southerly drift and the effluents were traced up to Sankhamugham. At other times, they moved towards north up to Thumba. The polluted patch had a width of about 0.5 km seaward from the shore.

Salinity of the surface waters at the stations covered ranged from 34.38 to 34.9‰ and temperature from

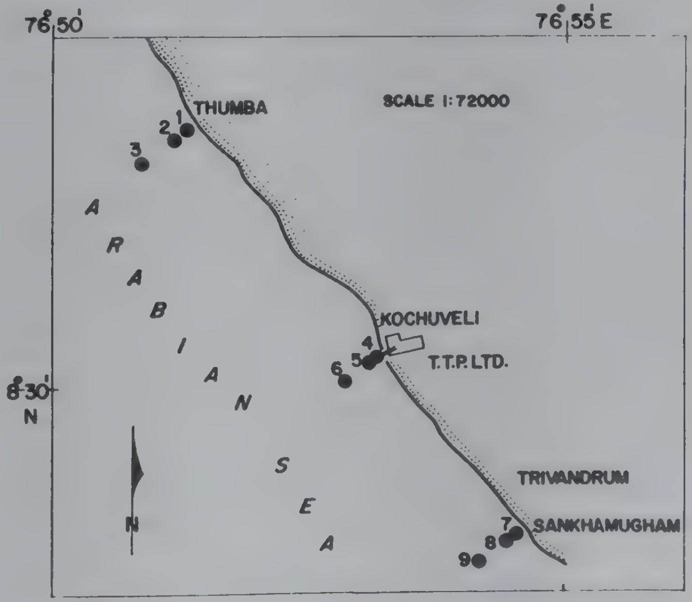

Fig. 1—Location of sampling stations

28.8 to 29.4°C. There was not much variation of these parameters during the period of collection of samples and their influence on the distribution of foraminiferal assemblages was not significant.

Temperature of the effluent as it came out of the factory, was about 45.8°C. At the region where the effluent mixed with the sea water on the shore it was about 36°C, and at the surf zone it was 29.1°C. Salinity of sea water at the site where the mixing with the effluents occurred was about 26.64‰.

*p*H of the effluent at the point of discharge was 1.4. In the vicinity of outfall area *p*H of sea water was 2 and seaward, away from discharge point, *p*H of sea water was > 7.5.

Results and Discussion

Eighty-five species of Foraminifera belonging to 42 genera under 26 families were identified. The percentage occurrence of individual species in total populations at the 9 stations for the 5 months was calculated. The abundant species along the coast were: *Miliolids*, *Elphidium* spp, *Neoconorbina patelliformis*, *Ammonia beccarii* (variants), *Operculina ammonoides*, *Amphistegina radiata*, *Nonion asterizans*, *Hanzawaia concentrica*, and *Hyalinea balthica*, and species which were rare being *Textularia candeiana*, *Trochammina nana*, *Clavulinoides jarvisi*, *Spiroloculina lucida*, *Sorites marginalis*, *Bolivina tortuosa*, *Legena perlucida*, *Rosalina concinna*, *Spirillina vivipara*, var. *runiana*, *Elphidium poeyanum*, *E. hispidulum*, *Cibicides cicatricosus*, *C. lobatulus*, *Planorbulinella larvata*, *Nonionella pulchella*, *Nonionella* cf. *grateloupi*, and *Gyroidina neosoldanii*.

Distribution of total population—The number of foraminiferal specimens per gram of dry sediment varied from 120 to 7720 showing consistently high values at stations 2, 5 and 9 particularly during December to April. Live specimens were more abundant at stations 2, 3, 6 and 9 when compared with stations 1, 4, and 7. No marked seasonal variations were noticed at stations 1, 3, 4 and 7 (Fig. 2 A). There was a general decreasing trend of Foraminifera in the offshore areas, except at station 9, with the increase in depth. Resig[5] and Cockbain[6] had also observed a similar trend.

Changes of the most abundant species which form the greater part of the total population are shown in Fig. 3. Miliolids are relatively less at the outfall area (station 4) in December and January and highest in March at station 3. There was gradual increase in concentration of miliolids away from the outfall area (with depth) along the traverse of T.T.P. *Ammonia beccarii* variants attained maximum population in January at stations 2 and 5. These forms, in contrast to miliolids, are pollution tolerant and decreased in abundance away from the shore along the transect of T.T.P. Another form, *Neoconorbina patelliformis* showed maximum abundance in April at station 1 and was almost absent at the site of outfall during the study. *Elphidium* spp and *Nonion asterizans* reached maxima in December and the abundance of the latter was comparatively poor along the traverse of T.T.P. *Operculina ammonoides* indicated maximum population at station 3 in December and January and the population of this species was somewhat poor along the traverse of T.T.P. The larger foraminifer, *Amphistegina radiata* increased in concentration at station 6 in December and the large sized foraminifers of this species were found in the offshore areas away from the region of outfall. The shallow water foraminifer, *Hanzawaia concentrica*, showed maximum population in April at station 5. *Hyalinea balthica* showed increased frequency at stations 1 and 4 in February at 5 m depth. Faunal abundance was independent of others with respect to monthly changes.

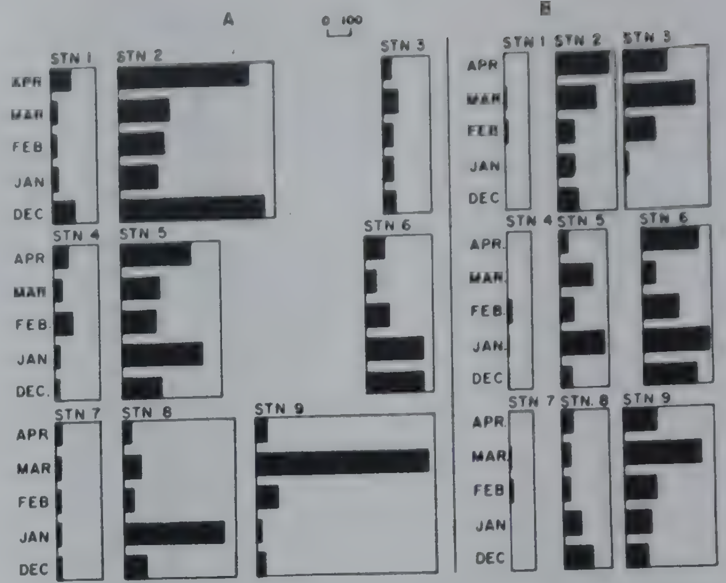

Fig. 2—Distribution of total (A) and living (B) populations of Foraminifera during December to April [Values indicate number of specimens/g dry sediment in A and number of specimens/g wet sediment in B]

Distribution of living populations—Living individuals were sporadic in their occurrence along the coast up to a depth of 5 m. As in the case of total population, living population also showed increase in abundance at some of the stations during February to April as compared to December (Fig. 2B). Living population increased in the offshore areas away from the T.T.P. discharge site (station 4). The most common living species along the coast were *Quingueloculina seminulum*, *Bolivina nobilis*, *Ammonia beccarii* variants, *Operculina ammonoides*, *Elphidium advenum*, *E. crispum* and *Nonion asterizans*.

Faunal groupings—Based on characteristic assemblages of Foraminifera, 3 faunal groups have been recognized, viz. beach, nearshore and offshore fauna which could be included in the respective depths of 0-1,

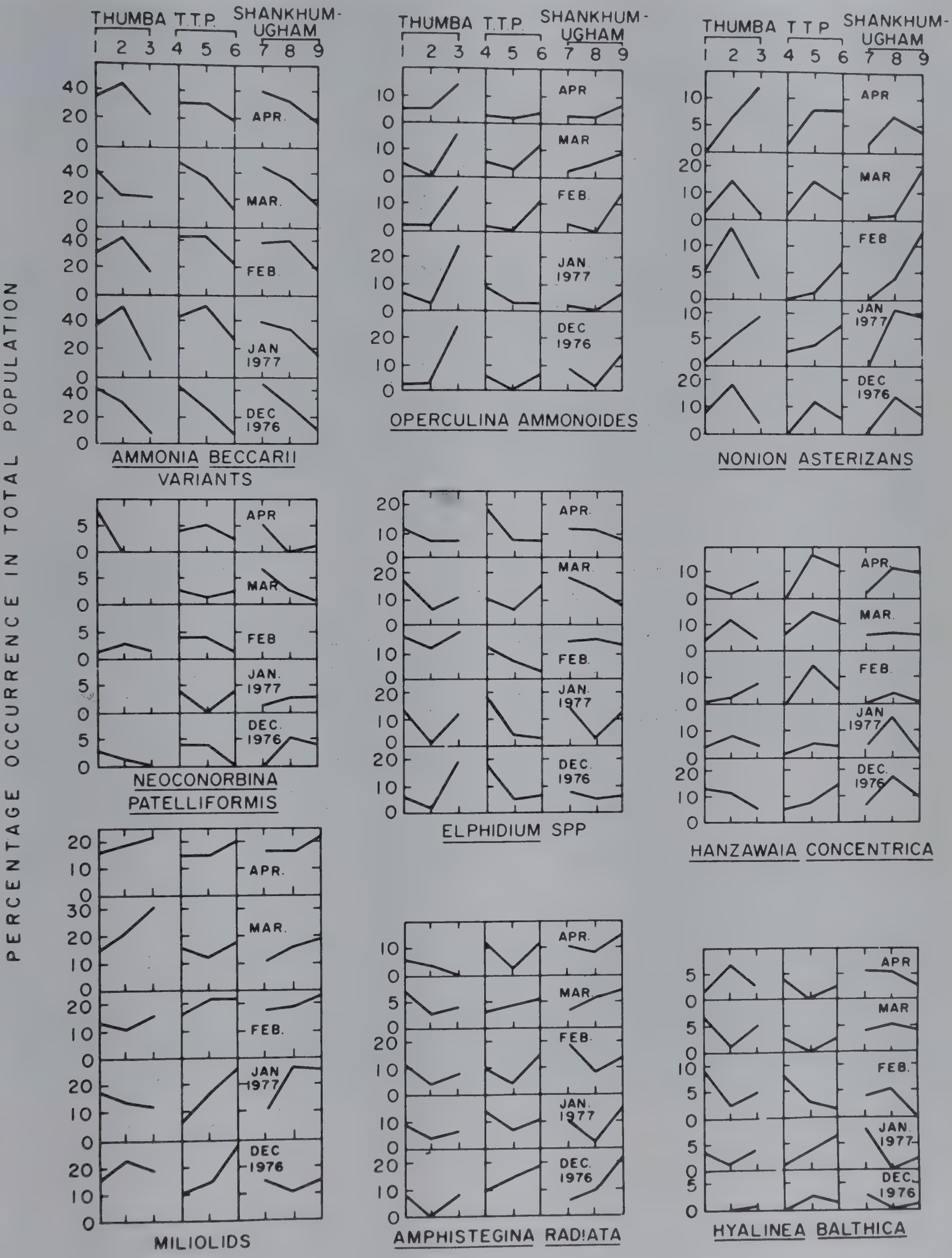

Fig. 3—Monthly distribution of abundant foraminiferal species in total population

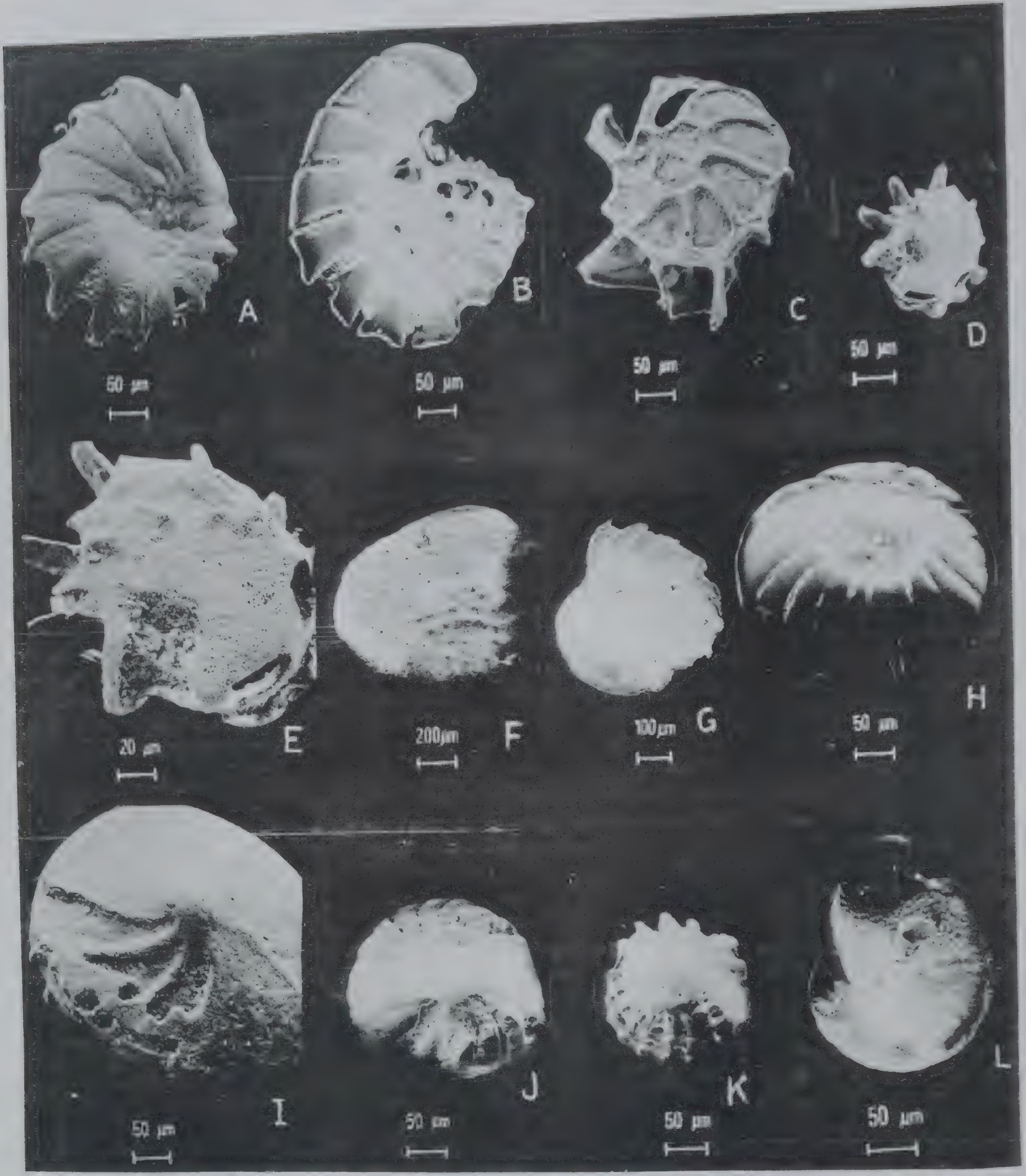

Fig. 4—Solution or corrosive effect shown on the surface of calcium carbonate foraminiferal tests by the acid wastes discharged from T.T.P. at the outfall area [A, *Peneroplis pertusus* (Forskal); B to E, *Ammonia beccarii* (Linne') variants; F, *Operculina ammonoides* (Gronovius); G, *Elphidium crispum* (Linne'); H, J & K, *Elphidium craticulatum* Fichtel and Moll; I, *Amphistegina radiata* (Fichtel and Moll); and L, *Hanzawaia concentrica* (Cushman)]

1-5 and 5-20 m. Similar faunal zones were defined by Todd and Bronnimann[7]. While the substratum of the nearshore region is mostly sandy, the sediments of the offshore region are either silty sand or sandy silt.

Beach fauna: It includes the dominant species *Ammonia beccarii* variants, *Poroeponides lateralis*, *Elphidium crispum*, *E. discoidale*, *E. craticulatum* and *Amphistegina radiata*, and the rare species *Operculina ammonoides*, *Peneroplis pertusus* and *Hanzawaia concentrica*. The specimens were in good state of preservation in the sand samples collected from Thumba and Sankhamugham but the surface of the test had been corroded or solution effect was seen in the case of specimens sorted from the material of polluted beach of Kochuveli where T.T.P. is located.

Nearshore fauna: This zone was characterized by the presence of forms like *Quingueloculina seminulum*, *Q. vulgaris*, *Neoconorbina patelliformis*, *Ammonia beccarii* variants, *Operculina ammonoides*, *Elphidium advenum*, *Amphistegina radiata* and *Nonion asterizans*. The presence of some offshore forms like *Lagena*, *Textularia* spp and planktonic Foraminifera could be attributed to the action of bottom currents and wave action.

Offshore fauna: Species diversity was relatively high in this zone as compared with other environmental zones of the coast and had a distinct assemblage of Textulariidae, Miliolidae, Soritidae, Nodosariidae, Bolivinitidae, Buliminidae, Rotaliidae, Elphiidae, Globigerinidae, Nonionidae and Anomalinidae.

Foraminifera as related to pollution—Foraminiferal studies concerned with marine and estuarine pollution in India and elsewhere were reported[8-17]. In the present study, an attempt was made to note the effects of industrial effluents on Foraminifera. It was observed that the nearshore waters of the Kochuveli beach were very much polluted due to the daily discharge of effluents in large volumes (1600 m^3/day) from T.T.P. The main constituents of effluents are sulphuric acid and ferrous sulphate, besides suspended material.

Near the acid waste dumping area and also on either side of the runnel formed on the beach by the effluent, flecks were observed with low *p*H values ranging from 1.4 to 2.5. No Foraminifera were found in the sand material beneath the acid fleck.

In order to study the effects of industrial effluents on Foraminifera, samples were collected from the polluted beach, stagnant pools on the beach formed by the effluents and also at the outfall area. Due to acid wastes along the coast the surface of the tests of Foraminifera was corroded. This was observed in the scanning electron-micrographs of Foraminifera specimens (Fig. 4). Some of the tests had chalky appearance, suggesting solution effect on their calcium carbonate content. Number of species was relatively less at the outfall area (station 4) as compared with the unpolluted sites (stations 1 and 7) at the same depth. The polluted sites near the vicinity of T.T.P. showed definite adverse effects on Foraminifera fauna and thus, as stated by Bandy[13], provided an ideal means of demonstrating relationships between marine animals and ocean pollution.

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Short Communications

Spectral Characteristics of Fine Structure Off the Mouth of Persian Gulf in the Northern Arabian Sea

K K VARMA, A A FERNANDES & L V GANGADHARA RAO

National Institute of Oceanography, Dona Paula, Goa 403 004

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Vertical profiles of temperature and salinity obtained from northern Arabian Sea using a STD profiler showed the presence of fine structure. The observed series from 3 selected stations were partitioned into mean and perturbation series using a high pass filter. Maximum fluctuations were observed in the thermocline. Spectral density of the parameters decreased with increasing wave number and exhibited a power dependence of about −3, at the lower wave numbers.

Fine structures in the northern Arabian Sea and the possibilities of different factors contributing to their formation have been discussed[1]. In the present paper an attempt has been made to study spectral characteristics of fluctuations of temperature, salinity and density with depth. Several investigators have studied the vertical spectra of these parameters[2−7], mainly the temperature.

Vertical profiles of temperature and salinity were obtained from a number of stations in the northern Arabian Sea during February 1974 using a Bisset-Berman STD profiler[1]. Three stations were selected for the present study. Stations 1 and 2 (23° N, 61°22.8′ E and 23°32′ N, 61°23′ E respectively) were studied because of their proximity to the mouth of Persian Gulf and the large variability of the individual traces, inspite of their closeness to each other. Station 3 (23° N, 64°05.3′ E) was chosen to see variations in the spectral characteristics, if any, with the distance from the source of Persian Gulf waters.

Temperature and salinity values were read from the analog records at every 10 m interval. Digitized data were checked against the data obtained from hydrographic casts and the necessary corrections incorporated. Density (σ_t) was computed using the tables for sea water density.

The observed series (with depth) can be considered as constituted by a mean series with the superimposed fluctuations

i.e., $T = \bar{T} + T'$

Thus the observed series can be split into mean series and perturbation series. This was achieved with the help of a high pass filter (11 point binomial filter with a cut off scale of about 100 m). Response characteristics of the filter are given by

$$\tau(k) = 1 - \cos^m (\pi \, k \, \nabla z)$$

where m is the exponential of the binomial, k the wave number and ∇z the sampling interval[8]. The original and perturbation series for station 1 are shown in Fig. 1.

Main features of the traces—At station 1, a large temperature inversion of about 0.8°C was observed in the thermocline, corresponding to which was an increase in salinity by about 0.8‰. The vertical scale of this feature was of the order of 80 m. The above feature of temperature was absent at station 2 and was replaced by an isothermal layer of about 50 m thickness. Salinity showed an increase of about 0.4‰

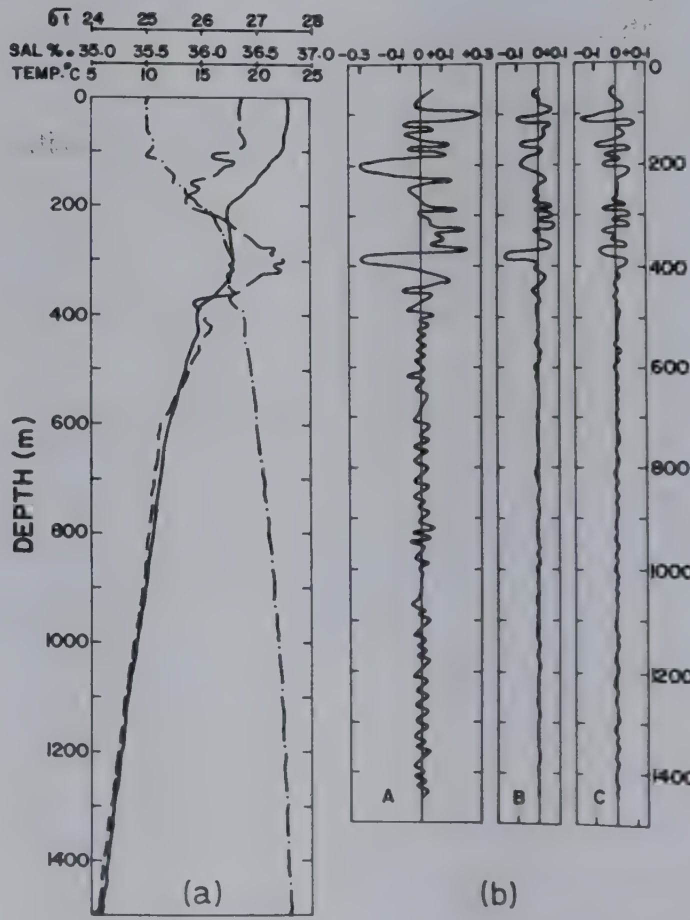

Fig. 1—(a) Depthwise distribution of temperature (———), Salinity (— — —) and density (—·—·—) at station 1. (b) Perturbation series of temperature (A), salinity (B) and density (C) at station 1

Station 3 was situated at about 275 km east of stations 1 and 2 and did not show any of the large temperature structures of the previous stations. A slight increase in salinity of about 0.2‰ was, however, present at about 300 m. At all stations sub-surface salinity minimum was noticed around 200 m depth, and below 300 m temperature and salinity decreased with depth.

Spectra of the high pass filtered data were computed by auto-correlation method[9]. Sampling interval of 10 m, used here, is rather coarse and may perhaps introduce errors into computed spectra by aliasing. However, the constraints of the analog record do not permit a closer sampling interval. As the spectra of these parameters are generally believed to decrease with increasing wave number even beyond the cut off wave number of the instrument (0.25 cpm), such contamination at lower wave numbers can be negligible. Hence the present attempt is to derive possible information with a note of caution. The data points were 141 and the maximum displacement used was 15 (df 18). The spectra were corrected for filter response and are presented on log-log scales in Fig. 2.

Temperature—The power densities at stations 1 and 2 were comparable at lower wave numbers, while the power density at station 3 was slightly less. The energy decreased with increasing wave numbers. For lower wave numbers, the decrease in power density at stations 1 and 2 up to 0.017 cpm had a slope of −3, while the decrease at station 3 up to 0.01 cpm was steeper (—3.9). Minor fluctuations at higher wave numbers were not significant (95% level).

Salinity—As in the case of temperature, power densities were comparable at lower wave numbers at stations 1 and 2 and were less at station 3. Slopes of the decrease of energy were about −3 up to 0.017 cpm at stations 1 and 2 and up to 0.01 cpm at station 3. Minor fluctuations at high wave numbers were not significant (95% level).

Density—The energy at lower wave numbers was less than those of temperature and salinity. Also, the energy at lower wave numbers was comparable at all stations. This is expected as the larger fluctuations of temperature and salinity have to cancel each other in order to avoid any significant unstable stratification. Spectrum at station 3 was rather steep up to 0.01 cpm compared to those at stations 1 and 2. Variations observed at higher wave numbers were insignificant (95% level). These spectra showed a similarity to the salinity spectra, though the similarity was less conspicuous at station 3. Roden[2] reported such a similarity between salinity and density spectra observed in the Pacific.

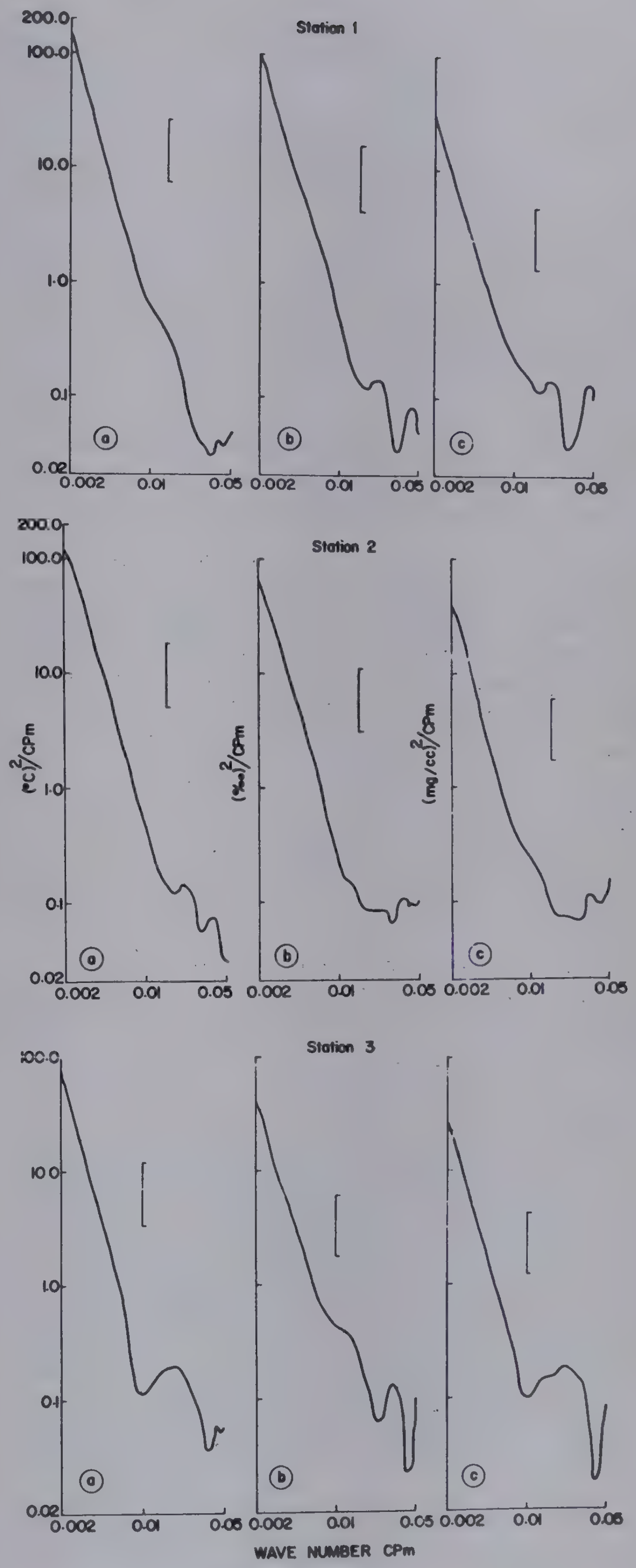

Fig. 2—Wave number spectra of (a) temperature, (b) salinity and (c) density (σ_t) at stations 1 to 3 [Bars indicate 95% confidence limits]

Several investigators have tried to relate the vertical wave number spectra to turbulence. The energy, derived from large scale motions, is passed down through a cascade fashion to be finally dissipated against viscosity. The effect of stratification is to damp the turbulence by working against buoyancy. In the thermocline, the region of maximum stability, vertical components of turbulence are inhibited and mainly the horizontal transfer of momentum takes place. If temperature and salinity are considered as passive scaler fields to be transferred along with momentum, maximum fluctuations can be expected in the thermocline. This is found to be true from the perturbation series (Fig. 1b).

The spectrum of turbulence, in the inertial subrange, will follow a $-5/3$ power law, while -3 power dependence is more appropriate in the buoyancy range[10]. Roden[2] has obtained for temperature and salinity, a relationship ranging from $-8/3$ to $-9/3$ between wave numbers 0.003 and 0.03 cpm. The present study shows a power dependence of about -3 for the lower wave numbers. This may perhaps be related to turbulence if temperature and salinity are considered as passive fields transported along with momentum. Pochapsky[11], following lagrangian method has observed a decoupling of turbulence from the mean flow at a horizontal scale of about 1 km. Even though such large scale decoupling does not seem to be possible in the vertical, the possibility of about few hundred metres cannot be ruled out.

It may be inferred from the above that the spectra of the parameters against the vertical wave numbers have a general similarity to those reported from many other oceanic regions. At station 3 an increase in spectral density was observed for all parameters at about 0.02 cpm (Fig. 2). Even though this was not significant at 95% level, it was conspicuous compared to the minor variations at stations 1 and 2. This feature together with lower energy levels and an increased slope at lower wave numbers at station 3 indicates that compared to stations 1 and 2 there can be some difference in the processes responsible for fine structure at station 3, situated further east from the mouth of Persian Gulf. Stations 1 and 2 had similar spectral structures, inspite of the variability observed in the individual traces.

The perturbation series are not homogeneous in amplitude (Fig. 1b). However, with this coarse sampling interval (10 m) it is not possible to divide the depth interval into homogeneous regions. Thus the reliability of determinations is not sufficient to attribute the results to any process in particular. A detailed study of different homogenous regions in the vertical together with current measurements is very much needed to ascertain the processes as the transfer of passive fields like temperature and salinity can be different from the momentum transfer.

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Clay Input from the Red Sediments of Visakhapatnam Coast

A T RAO & C V RAMAN

Department of Geology, Andhra University, Waltair 530 003

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Red sediments of recent age are commonly seen in association with the khondalite hill ranges and also found towards the coast in Visakhapatnam district. These red sediments comprise sand (quartz + heavies), silt and clay. X-ray data on clays reveal that kaolinite (70-94%) and illite (6-22%) are the dominant types in the red sediments. Smectite and chlorite are rare. Variation of clay mineral percentages in the red sediments is due to varying amounts of altered detrital sillimanite and orthoclase derived from the khondalites. The clays from the inner shelf have considerable proportion of illite and kaolinite along Visakhapatnam coast, which indicates that the fluvial input of clays from the red sediments and lateritic soils is significant.

Red sediments are prominent between the coast and the nearby khondalite hill ranges between Visakhapatnam and Bhimunipatnam. They are also found filling the valleys and resting on the slopes of hill ranges in the interior. These sediments are made of sand (quartz and heavies mainly magnetite, ilmenite, garnet, sillimanite and zircon) and ferruginous silt and clay. The sediments (Fig. 1) are of Recent age and their khondalite parentage is established in the light of statistical studies of zircons[1].

In the present investigation, influence of input of clays from red lateritic sediments and soils to the offshore region is studied based on the composition of clays and the formation of clays from the source minerals in the rocks.

Clays of $< 2\,\mu$ are separated from red sediments and X-rayed using Norelco X-ray diffractometer (Cu Kα

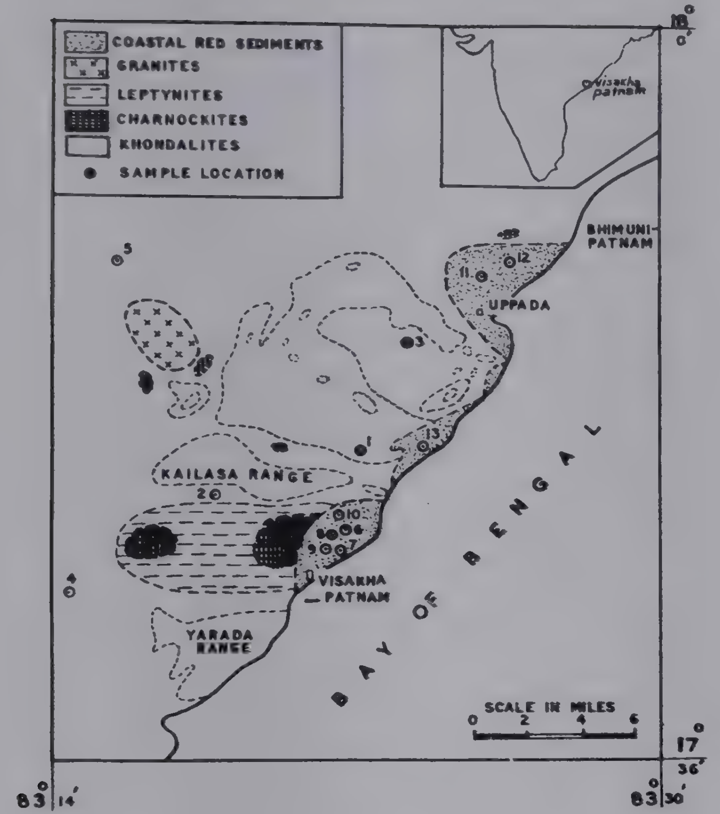

Fig. 1—Location of red sediments and associated rocks in Visakhapatnam and Bhimunipatnam areas

radiation) with a scan speed of 0.5° 2θ/min. Major clay mineral groups—kaolinite, illite, smectite and chlorite—were identified and their weighted peak area percentages calculated[2,3]. Percentage of clay minerals in the red sediments and semialtered khondalite zones in Visakhapatnam district is given in Table 1.

Clays from red sediments are kaolinite rich with appreciable amounts of illite. Smectite and chlorite are recorded as traces in a few samples. The clays in the red sediments contain 10-12% Fe_2O_3, which is uncombined in the structure, and which characterises the lateritic soils of Visakhapatnam district.

Origin of clays—Marked gibbsite formation from sillimanite (Fig. 2) needles and blades along fractures and cleavages in the khondalite exposures, especially in scarp zones of hill ranges around Visakhapatnam, is recognised. Garnet and orthoclase are found in incipient stages of alteration into gibbsite and illite respectively. Dry sub-humid climate of the area promotes chemical alteration as well as mechanical weathering. The red sediments occurring in the vicinity of the major khondalite hill ranges in the interior are the products thus derived and deposited on the slopes and in the valleys. Pronounced chemical alteration will take place in the sediments which are not transported effectively.

Feldspars are converted into illite in the presence of gibbsite which is formed from sillimanite or into kaolinite by the leaching of KOH and K^+. Sillimanite alters into gibbsite which in turn changes into kaolinite. The illite formed in well drained zones, such as Anantagiri and Chintapalli regions in Visakhapatnam district, will be readily carried away leaving kaolinite behind in the semialtered khondalite zones (Table 1). Greater illite and less kaolinite contents transported in suspension in the Sarada, the

Table 1—Percentage of Clay Minerals in Red Sediments and Semi-altered Khondalite Zones in Visakhapatnam District

S.No.	Percentage of mineral in 2 μ size fraction			
	Kaolinite	Illite	Smectite	Chlorite
	Inland red sediments			
1	80	18	2	—
2	84	16	—	—
3	85	10	3	2
4	80	20	—	—
5	94	6	—	—
	Coastal red sediments			
6	80	16	2	2
7	94	6	—	—
8	80	20	—	—
9	84	16	—	—
10	70	22	6	2
11	92	8	—	—
12	80	18	2	—
13	90	10	—	—
	Semi-altered khondalite zones in the bauxite deposits			
14	97	3	—	—
15	93	5	2	—

1-13 Sample locations shown in Fig. 1

14 and 15 are from Anantagiri and Chintapalle respectively in Visakhapatnam district

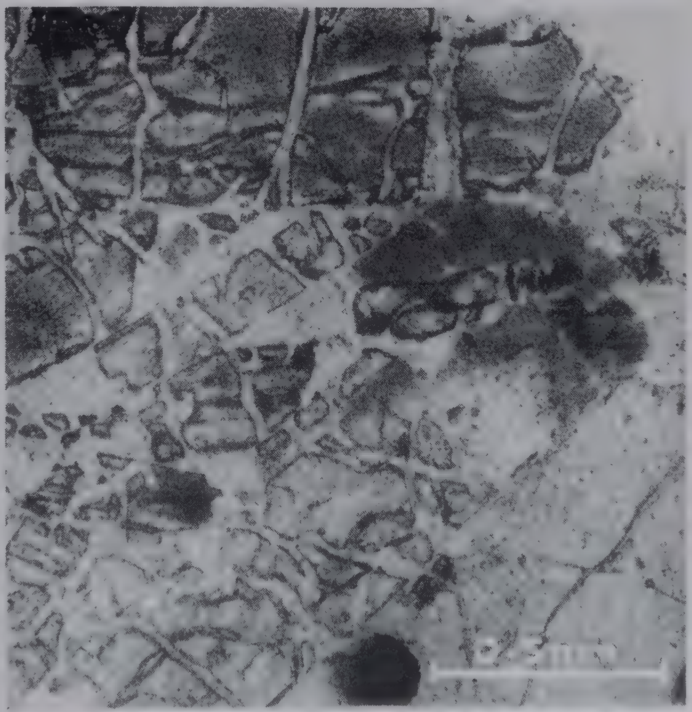

Fig. 2—Gibbsite development (net work) from sillimanite blades along fractures

Gosthani and the Godavari rivers support this observation[4]. The inland red sediments forming in poorly drained condition promote the conversion of feldspars and gibbsite into illite and are preserved fairly. The clays from coastal red sediments and inland red sediments have similar amounts of kaolinite and illite.

The khondalites in Visakhapatnam district are made of sillimanite, quartz and orthoclase (often perthitic) with accessory magnetite, ilmenite and zircon. The lithological variations of source rocks greatly influence the detrital mineral abundance or scarcity in the sediments. The wide range of feldspars (2-20% in the modal percentages of the rocks) found in khondalites will give erratic distribution pattern in the red sediments forming from the khondalites. Illite formation is directly related to the available feldspar content. Sillimanite is mainly responsible for the rich kaolinite (70-90%) concentration in the lateritic sediments and soils along the Visakhapatnam and Bhimunipatnam coast.

Input of clays into the Bay of Bengal—Shelf sediments of Visakhapatnam contain illite, montmorillonite, mixed-layer montmorillonite and illite, with a trace of chlorite, and kaolinite[5]. The inner shelf sediments of Recent age along Visakhapatnam and Bhimunipatnam coast[6] are characterised by dominating illite and kaolinite (75-85%) and less of smectite (< 25%). Presence of high amounts of kaolinite and illite in the red sediments adjacent to the coast suggest the ready input of clays into the shelf region.

Studies on shelf sediments[7] along Visakhapatnam coast, and the Godavari and the Krishna river estuaries along the east coast of India indicate clay mineral percentages of illite, 0-20; smectite, 70; kaolinite, 0-10; and chlorite, 0-10. The corresponding sediments in the Mahanadi region contain (%) illite, 20-30; montmorillonite, 30-50; kaolinite, 10-20; and chlorite, 10-20. X-ray analysis of clays from the deltaic and shelf sediments of the Mahanadi river shows 35-45% illite, 25-35% montmorillonite, 25-35% kaolinite and no chlorite[8]. Clays from the Godavari[9] river channel are rich in kaolinite (36-48%), montmorillonite (36-47%) and illite (16-20%) and in the estuary mouth, lagoon and mangrove swamp and deep marine environment the clays contain kaolinite (14-20%), illite (18-37%), montmorillonite (26-47%) and chlorite (20-22%). Kaolinite and illite rich (52-68%) sediments found in the Godavari river channel together with montmorillonite (36-47%) suggest that they are derived from both the laterite soils rich in kaolinite common in parts of Peninsular India and from smectite-rich Deccan Trap soils. The deep marine environment off Godavari river[9] has indicated appreciable amounts of kaolinite and illite (22% each). Based on the presence of good proportion of kaolinite and illite present in the river channel, delta and shelf region of the Godavari it may be said that though the head-waters of the Godavari are located in the poorly drained smectite rich Deccan Trap soils the input of lateritic soils formed on the granite gneisses and khondalites is considered very significant in view of the recent sedimentation.

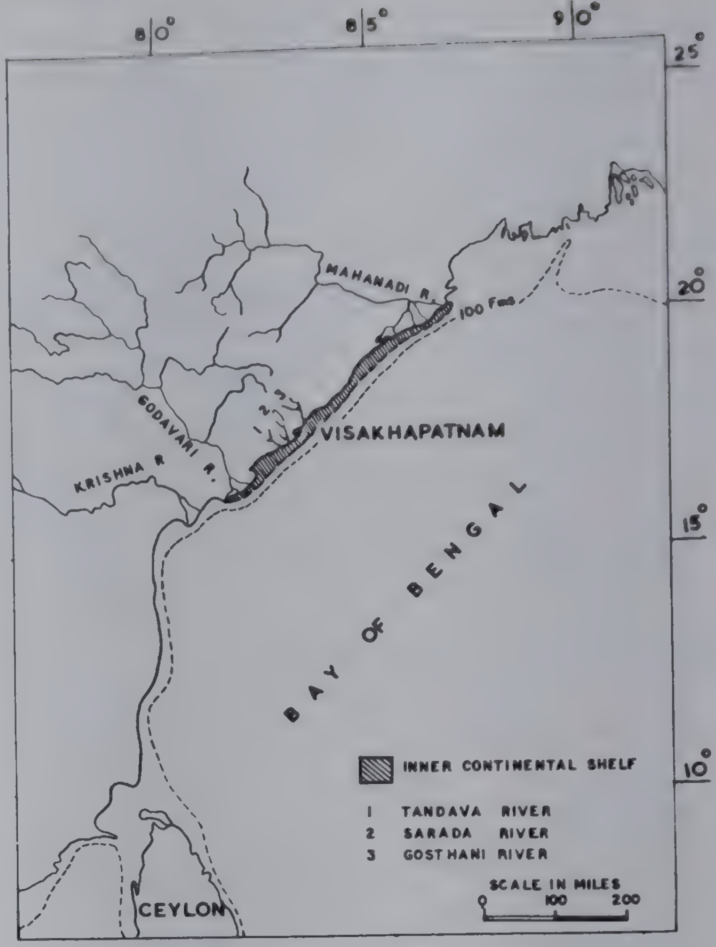

Fig. 3—Inner continental shelf sediments rich in illite and kaolinite (40-60%) in the clays from Mahanadi to Godavari region along the east coast of India

The Krishna river except for a small part in its upper reaches, and the Thungabhadra, it's important tributary, drains the Dharwar rocks mainly represented by granites and granite gneisses. It indicates that the red soils, derived from Dharwars, contribute fairly apart from the black Deccan soils in the Krishna region, similar to the Godavari sediments.

The high kaolinite and illite percentages in shelf sediments adjacent to coast right from the Mahanadi to the Godavari (Fig. 3) along the east coast of India is explained on the basis of greater fluvial input from the red lateritic soils, derived from the Precambrian granites and granite gneisses, which abound in the coastal tracts of the drainage basins.

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Toxicity of Effluent from a Titanium Dioxide Factory on Some Marine Animals

M MADHUPRATAP*, P HARIDAS, T C GOPALAKRISHNAN, V N SANKARANARAYANAN & P GOPALA MENON

National Institute of Oceanography, Regional Centre, Cochin 682018

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Toxicity of effluent from a titanium dioxide factory containing sulphuric acid residue with soluble iron metallic salts and insoluble material such as silica, etc. on fishes, decapods and molluscs was studied. The effluent caused changes in *p*H and oxygen depletion of the sea water. Sublethal effects of the precipitate of ferrous salts were also studied. Dilutions of effluent up to 1:150 were LC_{100} for all organisms used while 1:200 dilution was LC_{50} for fishes at 36 hr and for other organisms at 48 hr. But death of organisms at this concentration was caused by *p*H changes and O_2 depletion and did not account for the effects of the precipitate. Below this level precipitation started soon after mixing with sea water causing death of organisms by choking their gills and siphons. Dilutions $\leqslant$ 1:1000 were 96 hr LC_0.

Pollution of natural environments from a wide range of sources and pollutants have become an inevitable feature of the present day living. This is particularly true of the areas situated near heavy industrialisation and urbanisation. While the influence of pollutants on marine ecosystems is known to some extent, information regarding their nature of action and physiological changes on marine organisms is meagre. Toxicity tests have become important tools in determining the permissible levels of these pollutants in the environment and thus in the ecological monitoring of systems. A titanium dioxide factory situated at Trivandrum, Kerala, discharges its effluents into Arabian Sea through the beach. The rate of effluent discharge is about 1600 m^3/day and the waste (temperature of effluent at discharge point—45 to 50°C) having a pungent odour consists of a mixture of sulphuric acid (~3%) ferrous sulphate (10-40 g/litre) and insoluble materials such as silica and undissolved titanium dioxide. On mixing with the sea water, the ferrous sulphate gets oxidised to ferric form and precipitates as ferric hydroxide causing oxygen depletion and imparting a reddish brown colour to the sea water. The effluent spreads along the coastal waters as a patch and its direction depends on littoral drift. A survey conducted in 1976-77 has revealed[1] that there is a considerable depletion of the intertidal and benthic organisms in the area as a result of effluent discharge. Hence, it is felt necessary to conduct experimental studies to ascertain the levels of toxicity of the effluent.

A wide spectrum of animals were used for the studies consisting of fishes belonging to the genera [*Mugil, Salarias, Upenus, Chelilopion, Callydon, Chaetodon, Abudefduf, Pomocentrus* and *Chromis*], prawns [*Penaeus indicus* and *Metapenaeus dobsoni*], lamellibranch [*Donax* sp.], gastropod [*Terebra* sp.] and decapods [(Anomura) *Emerita* sp. and *Albunea* sp.].

Experiments were conducted after conditioning the animals in filtered sea water for 24 hr and introducing them into tanks (30 l) containing various concentrations of effluent diluted with filtered and aerated sea water. The effluent was collected freshly from the discharge point before dilution and was diluted for the experiment after cooling it to room temperature. Separate experiments were conducted with each group of animals using 10-15 for fishes and decapods and 25-30 for the molluscs. In experiments using molluscs and Anomurans bottom of the tank was filled with clean sand. Controls were set up with each experiment for comparison using the same filtered sea water. Measurements of *p*H were conducted with a *p*H meter and O_2 concentration by modified Winkler technique as described in Barnes[2]. During the experiments ambient temperature was maintained. Dilutions selected for the experiments (from 1:50 to 1:2000) covered a wide range of *p*H (2 to 7.5) to simulate the acid waste concentration and *p*H values observed in the actual area of effluent discharge. The area of effluent discharge was studied for 1 yr and it was observed that the *p*H of sea water at and near the point of mixing was as low as 2, although the *p*H rapidly increased in areas away from discharge point. Toxicity of the effluent was assessed from its lethality on the animals.

Death of organisms from the effluent can be due to severe changes in *p*H of water, asphyxiation owing to oxygen depletion and prolonged sublethal effects of the precipitate suspension in the water column. Sulphuric acid is known to be harmful to marine organisms even at very low concentrations[3]. Oxygen concentration and *p*H of the sea water were drastically affected by the effluent (Fig. 1). Experiments showed that dilutions of the effluent up to 1:150 (*p*H 4.1, oxygen concentration (29.5%) were lethal within 2 to 10 min. Below this, varying degrees of stress conditions were observed

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*Present address: National Institute of Oceanography, Dona Paula, Goa 403004

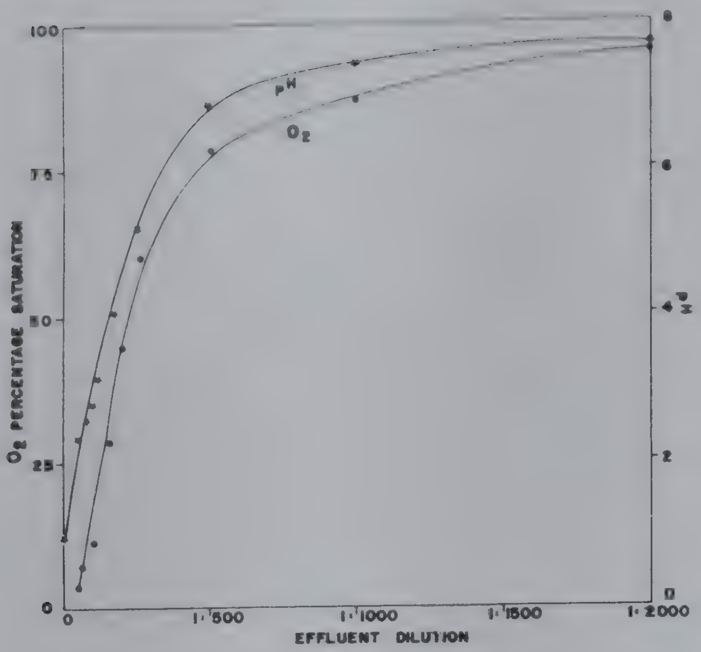

Fig. 1—Changes in pH and oxygen percentage saturation at different dilutions of the effluent

depending on the organism and concentration of the effluent; effluent affected the organisms in 2 ways—(i) due to lowering of pH and (ii) due to formation of precipitate. Dilution of 1:200 although observed not to cause immediate death of organisms caused stress. Many of the fishes tried to jump out on introducing them to the experimental tank. Later they became sluggish and soon moribund. Death of fishes introduced into this medium occurred in about 36 hr.

Dilution 1:200 was LC_{50} for fishes at 36 hr and for decapods and molluscs at 48 hr. The lamellibranchs which initially burrowed into the sand and had their siphons out, came out of the sand after sometime and closed their shells. Later the shells opened probably owing to the inactivation of the adductor muscles and the animals died. But these reactions did not include the reaction of the organisms to precipitate and its effects since precipitation at this concentration started only after 30 to 35 hr when the pH increased to 5.6 after 30 hr.

At 1:250 dilution, precipitation started after about 2 hr and death of organisms occurred within 5 to 8 hr. The gills of the fishes and decapods and siphons of molluscs were heavily deposited with the precipitate. The shells were also stained with it. It has been shown[4] that metals act on gill surfaces causing thickening of the epethelial walls resulting in death by asphyxiation. Even otherwise sufficient quantities of precipitate gathered in the gills and siphons would impair the respiratory and feeding mechanisms of these organisms. At 1:500 dilution precipitation started immediately but organisms survived 20 to 40 hr owing to the lower concentration of the precipitate.

Experiments were conducted by adding sulphuric acid to sea water to bring the acid content to levels imparted by various concentrations of the effluent. It was found that at 1:150 dilution (as of the effluent) the animals although survived a little longer than those at the same concentration of the effluent, died within 30 min to 1 hr confirming that the severe pH changes affect the organisms. Experiments conducted after bringing the effluent concentration to 1:250 and neutralising it to raise the pH to 7.1 showed immediate precipitation and the animals displayed stress conditions and were moribund within 5 to 6 hr. The precipitate after settling to the bottom was not seen to be avoided by fishes or prawns although the molluscs which are sedentary clustered in the places without precipitate.

It has been observed[5] that in spite of considerable accumulation of Fe-oxide-hydrate flakes directly above the sediment, settlement of new species or larvae of polychaetes were not hindered. But long term experimental studies[6] on mussels fed with ferric hydroxide flakes showed loss of body weight and high mortality rate among them. Substantial mortality of adult copepods in laboratory experiments to study effects of acid-iron wastes were observed[7] at pH 6.5 and less. Acute toxicity tests using different metals[8] had shown iron to be less toxic than other metals like mercury, copper or chromium with 48 hr LC_{50} for brown shrimp *Crangon* to be between 33 and 100 ppm and for European cockle *Cardium edule* between 100 and 330 ppm.

Dilutions of 1:1000 and 1:2000 over a period of 96 hr were safe for all types of organisms used, in spite of constant mixing of the water to keep the precipitate in suspension. Survival rate of 100% was observed in all controls used.

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Pollution in Cochin Backwaters with Reference to Indicator Bacteria

P S GORE, O RAVEENDRAN & R V UNNITHAN

National Institute of Oceanography
Regional Centre, Cochin 682018

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Quantitative abundance of indicator bacteria, viz. coliforms, *Escherichia coli* and *Streptococcus faecalis*, in sediment and water samples from 6 sewage outfall stations of Cochin backwaters is studied for 1 yr. FC/FS (faecal coliform/faecal streptococci) ratio indicates that the principal source of faecal pollution is non-human type originating from land drainage, discharge of organic waste and also from sewage discharge. Based on quantitative abundance and distribution of these organisms the 6 stations are classified as intensely polluted, fairly polluted, and slightly polluted. Consumption of edible animals obtained from the Cochin estuarine environment, as a source of health hazard is highlighted.

Data on pollution of Cochin backwaters are meagre[1,2]. Sewage imparts considerably to the quantity of faecal microorganisms, which principally forms potential health hazard. Therefore, it is essential to understand the magnitude of faecal pollution in the environment. Information on faecal pollution of Cochin backwaters is scanty[3,4] and hence merits a detailed investigation. In this paper, based on data collected during June 1975 to May 1976, quantitative occurrence of indicator organisms like coliforms, *Escherichia coli* and *Streptococcus faecalis* in surface water and sediment samples is presented.

Surface water and bottom sediment samples were collected at fortnightly intervals from June 1975 to May 1976 from 6 selected shallow water stations (1, 2, 4 to 7 as indicated earlier[1]) with an average depth of $1\frac{1}{2}$ m, from near the opening of the major canals into the Cochin backwaters. The sediment was collected using a Peterson Grab. A sample was taken from the central portion of the mud in the grab and transferred into sterile sampling petri dishes using a spatula. A plastic bucket was used for collecting water samples from the surface. The samples were held at 0°C on board and transported to the laboratory for plating within 5 hr of collection. Details of plating procedure, enumeration technique, preparation and composition of different media used were same as given earlier[5]. Standard statistical methods were employed to study variance[6]. FC/FS (faecal coliform/faecal streptococci) ratio was calculated from counts both in water and sediment samples for various stations and different months as suggested by Finstein[7].

S. faecalis, coliforms and *E. coli* occurred regularly in considerable numbers in all stations, both in sediment and water (Table 1).

Streptococcus faecalis—They were less in number in monsoon months (May to July). In general, higher counts were encountered in sediment samples than in water samples suggesting that they are adsorbed by the sedimentary particles and can survive long periods. Counts of *S. faecalis* ranged from 0 to 22/ml in water and 0 to 40/g in sediment. Highest counts were recorded from st. 1 both in water and in sediment.

The data were subjected to analysis of variance to study whether these organisms vary between stations and between months. Abundance of *S. faecalis* varied significantly between months and between stations at 0.1 % level. The analysis showed highest incidence at st. 1 followed by st. 4. November 1975 and February to April 1976 were the peak periods of incidence for the water samples. Sediment samples showed significant variations between months at 0.1 % level while between stations variations were not significant. Peak months of incidence for sediment samples were November 1975 and January to April 1976.

Escherichia coli—They showed erratic distribution both in sediment and in water and also with reference to different stations and months. High counts were recorded in June and October. The pattern of occurrence was just the reverse of that of *S. faecalis*, in that higher counts were noticed in water than in sediment. The counts ranged from 0 to 98/ml in water and 0 to 22/g in sediment. As in *S. faecalis*, here also highest counts were encountered from st. 1 both in sediment and water.

Analysis of variance showed higher counts in st. 1 followed by st. 2, 4 and 5. June and October 1975 were the peak months of incidence in water. For sediment samples, the peak months of incidence were December 1975 to June 1976 and st. 1 followed by st. 4 recorded highest incidence. There was significant variation between stations at 1% level while between months it was significant at 0.1% level. A decline of *E. coli* and coliform counts was recorded[3] in monsoon months. In the present study also higher counts were obtained in monsoon month (June). However, higher counts were recorded in postmonsoon months also. Bonde[8], while studying the faecal coliform counts of the sediments from Oresound found that the counts decreased with depth. In the present study no such relationship with depth was noticed because the stations were shallow. Rittenberg *et al.*[9] reported *E. coli* and coliform counts to be higher in sediment than in water from the California marine sewage outfall. This is markedly different from the present results, mainly because of the shallow nature of the sampling area.

Coliforms—Quantitative occurrence of coliforms were more in water than in sediment as in the case of *E. coli*. Higher incidence was recorded in premonsoon (February) and monsoon (May and June). As in the previous cases st. 1 recorded highest counts both in water and in sediment. The counts ranged from 5×10^3

Table 1—Incidence of Coliforms, *E. coli* and *S. faecalis* at Different Stations
[Results are expressed per ml for water samples (W) and per gram for mud samples (M)]

Month	Coliforms ($\times 10^3$)		*E. coli*		*S. faecalis*		Coliforms ($\times 10^3$)		*E. coli*		*S. faecalis*		Coliforms ($\times 10^3$)		*E. coli*		*S. faecalis*	
	W	M	W	M	W	M	W	M	W	M	W	M	W	M	W	M	W	M
			Station 1						Station 2						Station 3			
June '75	210	11	98	19	8	9	118	16	33	10	3	nil	120	9	21	1	2	nil
July '75	42	5	32	6	1	6	22	3	nil	nil	nil	2	17	2	1	4	1	2
Aug. '75	8	5	10	4	6	nil	32	12	2	nil	nil	3	11	16	2	7	1	2
Sept. '75	12	24	4	6	3	6	15	18	5	8	2	3	28	20	4	5	2	3
Oct. '75	20	28	37	nil	3	2	24	20	46	nil	4	3	26	18	7	nil	2	3
Nov. '75	124	68	22	10	22	19	62	12	12	1	12	11	140	69	14	9	16	17
Dec. '75	210	122	41	22	16	21	110	28	8	8	10	13	118	89	12	5	7	11
Jan. '76	96	48	12	16	12	26	42	20	8	3	3	11	78	42	11	9	8	17
Feb. '76	260	136	36	10	22	40	112	21	12	6	10	30	218	39	12	8	12	20
March '76	128	31	17	14	18	28	58	22	8	4	8	12	90	30	11	3	10	21
April '76	112	56	16	17	14	18	75	48	11	10	8	7	93	42	7	5	12	18
May '76	131	72	14	nil	20	20	118	28	5	nil	10	22	118	74	nil	nil	nil	nil
			Station 4						Station 5						Station 6			
June '75	172	10	20	2	2	nil	235	11	30	4	nil	nil	108	10	28	nil	nil	nil
July '75	13	9	4	3	1	2	7	8	nil	nil	1	nil	10	12	nil	3	nil	nil
Aug. '75	23	9	3	10	3	2	5	12	2	4	nil	4	8	11	nil	1	nil	3
Sept. '75	20	12	4	5	3	2	10	11	2	3	1	3	15	8	3	5	1	3
Oct. '75	21	11	33	nil	3	2	8	12	66	nil	1	4	12	10	34	nil	1	3
Nov. '75	73	22	8	4	15	17	11	12	8	2	6	13	14	14	1	1	6	8
Dec. '75	120	61	9	7	9	11	20	112	10	12	8	10	70	15	7	12	2	3
Jan. '76	71	35	8	11	11	15	92	30	6	9	5	17	24	21	2	8	2	8
Feb. '76	205	37	14	5	11	30	104	31	10	5	12	25	91	24	8	3	8	20
March '76	110	72	15	8	16	13	123	35	11	9	14	22	81	23	18	8	8	12
April '76	82	63	13	7	14	15	102	53	10	15	11	8	62	38	9	10	9	7
May '76	102	88	5	4	12	20	82	72	nil	nil	nil	nil	73	36	nil	nil	nil	nil

Table 2—FC/FS Ratio of Water (W) and Mud (M) in Cochin Backwaters from June 1975 to May 1976

Month	Station 1		Station 2		Station 3		Station 4		Station 5		Station 6	
	W	M	W	M	W	M	W	M	W	M	W	M
1975												
June	12.2[a]	2.1[a]	11[a]	10[a]	10.5[a]	1[b]	10[a]	2[a]	30[a]	4[a]	28[a]	0
July	32[a]	1[b]	—	0	1[b]	2[b]	4[a]	1.5[b]	0	—	—	3[a]
Aug.	1.66[b]	4[a]	2[a]	0	1[b]	3.5[a]	1[b]	5[a]	2[a]	1[b]	—	0.33[b]
Sept.	1.33[b]	1[b]	2.5[a]	2.6[a]	2[a]	1.6[b]	1.33[b]	2.5[a]	2[a]	1[b]	3[a]	1.6[b]
Oct.	12.3[b]	0	11.5[a]	0	3.5[a]	0	11[a]	0	66[a]	0	34[a]	0
Nov.	1[b]	0.5[b]	1[b]	0.09[b]	0.8[b]	0.5[b]	11[a]	0	2[a]	1[b]	3[a]	1.66[b]
Dec.	2.56[a]	1.04[b]	0.8[b]	0.06[b]	1.7[b]	0.45[b]	1[b]	0.63[b]	1.2[b]	1.7[b]	3.5[a]	4[a]
1976												
Jan.	1[b]	0.6[b]	2.6[a]	0.27[b]	1.37[b]	0.5[b]	0.7[b]	0.73[b]	1.2[b]	0.52[b]	1[b]	1[b]
Feb.	1.6[b]	0.25[b]	1.2[b]	0.2[b]	1[b]	0.4[b]	1.3[b]	0.16[b]	0.83[b]	0.2[b]	1[b]	0.15[b]
Mar.	0.94[b]	0.5[b]	1.0[b]	0.3[b]	1.1[b]	0.14[b]	0.93[b]	0.6[b]	0.7[b]	0.8[b]	1.5[b]	0.66[b]
Apr.	1.14[b]	0.8[b]	1.37[b]	1.4[b]	0.57[b]	0.27[b]	0.9[b]	0.47[b]	0.9[b]	1.8[b]	1[b]	1.4[b]
May	0.7[b]	0.1[b]	0.6[b]	0	—	—	0.4[b]	0.2[b]	—	—	—	—

a= human and b= non-human

to 260×10^3/ml in water and 2×10^3 to 136×10^3/g in sediment samples.

Analysis of variance showed a significant variation between stations at 0.1 % level. The highest incidence was recorded in st. 1 followed by st. 3, 4 and 2 while the peak months of incidence were June 1975, February and May 1976 in the water samples. In sediment samples, between stations variation was not significant at 5% level. Peak months of occurrence were December 1975, April and May 1976. A declining trend of coliform incidence during monsoon and higher counts during premonsoon months were reported[3] and the latter observation agrees with the present.

FC/FS ratio—FC/FS (Table 2) ratio revealed no regular pattern from month to month or from station to station. Human faecal pollution was dominant (ratio > 2), both in sediment and in water during June 1975 only, while in rest of the months it was non-human type (ratio < 2) in sediment samples except in August. Human faecal type pollution was recorded in water during September to November 1975, while rest of the months it was non-human type. Highest (66) ratio was recorded in October 1975, in st. 5 in water.

The importance of FC/FS ratio in interpreting the faecal pollution of a given watermass was suggested by several authors[10-12]. Geldreich and Clarke[13] while giving preference to FC/FS ratio in assessing and indicating human and non-human faecal pollution emphasised the importance of collection of samples from the nearest location of sewage outfall to formulate the ratio. In the present investigation also FC/FS ratio was calculated as per Geldreich and Clarke. Based on the quantitative occurrence of indicator group of bacteria (Table 1) the 6 stations could be classified into intensely polluted (st. 1), fairly polluted (st. 5, 4 and 3) and slightly polluted (st. 2 and 6) areas, which agrees with the earlier observations[1,2].

Occurrence of faecal coliform in water and sediment, is regarded as a single important indicator of public health hazard. These organisms get ingested into the body of filter-feeding organisms, bottom dwelling fish, prawns, bivalves, etc., rendering them potential carriers and making them unfit for human consumption. Geldreich and Clarke[13] reported that the occurrence of coliforms in water or mud signifies the potential presence of other enteric pathogens in the same environment. It is, therefore, obvious that the extent of occurrence of *E. coli*, coliforms and *S. faecalis* in the Cochin backwaters warrants thorough bacteriological quality control of edible animals marketed.

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Isolation & Identification of Luminous Bacteria from Porto Novo Estuarine Environs

G BALAKRISH NAIR, MARTIN ABRAHAM & R NATARAJAN

Centre of Advanced Study in Marine Biology, Annamalai University, Parangipettai 608 502

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A survey on the occurrence of luminous bacteria was carried out in the Vellar estuary for over 4 months and 105 strains of bacteria were isolated and identified using diagnostic tests. Ninetyeight strains were identified as *Beneckea harveyi*, 2 as *Photobacterium fischeri* and 5 as *P. leiognathi*. *B. harveyi* was isolated from all samples while *P. fischeri* and *P. leiognathi* showed restricted distribution.

Luminous bacteria occupy a variety of niches in the marine milieu. The functional significance of symbiotic luminescent bacteria is well documented[1-3] but the role of luminescence in 'free living' bacteria requires elucidation. Since the proposal of Beijerinck[4] that all luminous bacteria should be placed in one genus, *Photobacterium*, there has been a lot of confusion regarding their taxonomic status. However, in recent years extensive taxonomical studies[5-7] have stabilised this conflicting situation. Currently their identification is based on few simple diagnostic tests. Information on luminescent bacteria from Indian waters is scarce. Jayabalan *et al.*[8] have recorded the presence of luminescent bacteria from the light organs of 4 species of silver bellies (family: Leiognathidae) from Porto Novo. Results of a survey on 'free living', saprophytic and enteric luminescent bacteria from Porto Novo estuarine environs are presented here.

Sampling and isolation—Twenty four samples of estuarine surface water were collected at high tide between 8 May and 26 August 1978, at weekly intervals from the Vellar estuary, Porto Novo (11°29′ N; 79°49′ E). In the earlier part of this study, isolation of luminescent bacteria was facilitated by direct plating of water samples in salt water yeast extract medium containing (%) peptone, 1; yeast extract, 0.3; NaCl, 2.4; $MgSO_4.7H_2O$, 0.7; $MgCl_2$, 0.53; KCl, 0.07 and agar-Difco, 1.5; *p*H 7.4 ± 0.2. Later, isolation technique described by Ruby and Nealson[9] was followed with some modifications. This involves the use of a complex sea water medium (SWC) containing 750 ml sea water, 250 ml distilled water, 3 ml glycerol, 5 g bactopeptone and 3 g yeast extract. For a soft agar SWC 7 g/litre and for solid SWC medium 12 g/litre Difco agar was added. Approximately 25 ml of water sample was collected in sterile conical flask, of which 2 ml was mixed with 4 ml molten soft agar SWC (40°C), kept in sterilized 10 ml tubes and the mixture immediately spread plated on solid SWC agar plates. Six replicates were plated for each sample and after solidification of the overlay, one set (3 plates) was incubated at 25° ± 1°C and the other at 35° ± 1°C. After 36 hr incubation, plates were examined for the presence of luminous colonies in dark. Luminous colonies were marked on the outer surface of the lower dish of plates with glass marking felt pens. The plates were observed again after 48 hr for additional luminous colonies. The marked colonies were picked out using sterile toothpicks and streaked on SWC agar plates using the flat, broad end of the toothpick. Single bright luminous colonies so obtained were subcultured on SWC slants and maintained at room temperature for further characterization. Fish and shellfish (only crabs and prawns), caught from the estuary using a cast net, were immediately transferred into sterile polythene bags and transported to the laboratory in an insulated container. All specimens were examined within 4 hr of collection by swabbing the gills, external surface and intestinal contents (only for fish) using sterile cotton tipped applicator sticks and streaking on SWC agar plates. For each region of the sample, 2 plates were prepared, one incubated at 25° ± 1°C and the other at 35° ± 1°C. After incubation (36 and 48 hr) luminous colonies were isolated using the same procedure and maintained in SWC slants for further characterization.

Identification of isolates—A total of 16 tests were performed for 105 luminescent isolates obtained (Table 1). The ability to use 8 organic compounds as sole source of carbon, production of extracellular enzymes and the other tests were performed as described by Nealson[10]. The nomenclature established by Reichelt and Baumann[6] was followed.

Incubation period of 36 hr was ideal in the present study for isolation of luminous bacteria with no additional luminescent colonies appearing on reobservation at 48 hr. This concurs with the findings of Ruby and Nealson[9]. Recovery of luminescent bacteria from water samples was enhanced when the isolation technique of Ruby and Nealson[9] was used and the method was more suitable than the direct plating technique.

Table 1—Diagnostic Characters Used for Identification of Luminous Bacteria

[Figures in parentheses indicate total number of strains characterized]

Test	Response		
	B. harveyi (98)	*P. fischeri* (2)	*P. leiognathi* (5)
Gram stain	–	–	–
Growth at:			
4°C	–	–	–
35°C	+	+*	+
Growth on:			
Maltose	+	+	–
Cellobiose	+	+	–
Gluconate	+	–	+
Glucuronate	+	–	–
Mannitol	+	+	–
Lactate	+	–	+
Acetate	+	–	+
Propionate	+	–	–
Production of extra-cellular enzymes			
Amylase	+	–	–
Lipase	+	–	–
Gelatinase	+	–	–
Other traits:			
Gas from glucose	–	–	–
Yellow pigment production	–	+	–

*Strains showed very weak growth

Table 2—Isolation of Luminous Bacterial Species from Different Sources

[Numbers in parentheses indicate total number of organisms sampled]

	No. of samples screened	No. of luminous strains isolated	Species		
			B. harveyi	*P. fischeri*	*P. leiognathi*
			Water sample		
	24	15	11	2	2
			Fish (65)		
External surface	65	22	22	—	—
Gills	65	14	14	—	—
Intestinal contents	65	36	33	—	3*
			Crustaceans (prawns & crabs only; 36)		
External surface	36	12	12	—	—
Gills	36	6	6	—	—
Total	291	105	98	2	5

*Two strains isolated from *Leiognathus* sp. and one from *Secutor insidiator*

Five species belonging to 2 genera of marine luminous bacteria, viz. *Beneckea harveyi*, *B. splendida*, *Photobacterium fischeri*, *P. leiognathi* and *P. phosphoreum*, are known[3]. In the present study 3 species belonging to 2 genera were found in Porto Novo environs (Table 2). *B. splendida* and *P. phosphoreum* could not be detected probably due to their exacting temperature requirement or restricted distribution.

B. harveyi was the dominant species accounting for 93% of the luminous strains isolated. Isolation of this species from all the samples suggest their ubiquitous distribution. All the 98 isolates of *B. harveyi* utilized 8 organic compounds used (Table 1) as sole sources of carbon and energy, signifying a high nutritional versatility. Reichelt and Baumann[6] reported that *B. harveyi* can utilize about 40 different organic compounds as carbon and energy sources. According to Hastings and Nealson[1], the nutritional profile of *B. harveyi* when compared to *Photobacterium* species was far more versatile, indicative of a more cosmopolitan species. Predominance of *B. harveyi* in the nearshore waters of Southern California in summer was reported by Ruby and Nealson[9], as found presently in tropical waters. High frequency (51%) of occurrence of *B. harveyi* from intestinal contents of fish implies that this species prefers an enteric habitat. One strain of *B. harveyi* produced opaque nonluminous and translucent luminescent variants.

Only 2 strains of *P. fischeri* could be isolated and in one, luminescence was irreversibly lost during storage. Both strains showed weak growth at 35°C though at 30°C, growth was greatly accelerated. This species produced a yellow-cell-associated pigment and both these strains were isolated from plates incubated at 25° ± 1°C indicating a low temperature preference.

Despite the fact that *P. leiognathi* are found principally as light organ symbionts of leiognathid fishes, their isolation from water samples as discernible from the present survey, is not anamolous. Isolation of *P. leiognathi* from seawater has been reported[5,6]. Hastings and Mitchell[11] have suggested that since cells are maintained in exponential phase in the light organ, there is every possibility of excess cells passing out of ducts communicating with the gut and in such cases they are merely the escaped forms and not true saprophytes.

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Stomach Contents of *Portunus pelagicus* (Linn.) from AD Net Catches

N M PATEL, N D CHHAYA & M BHASKARAN
Marine Biological Research Station, Port Okha 361 350

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Stomach contents of *P. pelagicus* studied during May to September 1975 consist of crustaceans, molluscs, fishes, zooplankton and phytoplankton (24.97, 24.96, 9.43, 0.65 and 0.95% respectively). The results suggest its bottom feeding habits and sandy-muddy coast habitat.

An AD net (stake net) made from cotton No. 4 (ref. 1) is used for coastal fishing at Sikka (lat. 22°29′ N, long. 69°51′ E) from May to September. The major catch of this net is the portunid crab, *Portunus pelagicus* (Linn.). Though some biological aspects of *P. pelagicus* have been studied[2], the stomach contents of this species have not been studied so far. This communication reports the stomach contents of *P. pelagicus* caught in AD net.

In each month from May-September 1975, 100 specimens of *P. pelagicus*, ranging 71-147 mm carapace width, from AD catches were brought to laboratory. The crabs were dissected and stomachs removed and preserved in 5% formalin. The volume of stomach contents was determined by the displacement method.

The stomach contents of *P. pelagicus* are represented (%) by zooplankton (copepoda, foraminifera), 0.65; phytoplankton (diatoms), 0.95; fishes, 9.43; molluscs, 24.96; crustaceans, 24.97; miscellaneous items, 14.2; and semidigested food, 24.84.

Different components observed during May to September in the stomach of *P. pelagicus* are given in Table 1.

Crustaceans—Prawn body parts and crab body parts were observed in all 5 months in more or less same quantities but barnacle parts were observed in May.

Table 1—Percentage Composition of Different Stomach Components of *P. pelagicus* from May to September 1975

Components	May	June	July	Aug.	Sept.
Crustaceans					
Prawn body parts	5.96	3.35	18.52	7.2	15.45
Small crab pieces	13.1	12.65	8.4	17.4	25.2
Barnacle pieces	0.3	—	—	—	—
Molluscs					
Conus sp.	0.3	—	—	—	—
Trochus opercles	2.53	0.5	1.8	15.75	7
Nerita albicilla	—	—	—	0.03	—
Turritella cutaugulla	—	—	—	0.15	—
Other gastropod shell pieces	1.2	8.25	4	2.7	1.5
Bivalve shell pieces	36.6	7.5	11.2	14.7	12
Fishes					
Scales	—	—	3	10.8	15
Bones	0.48	0.1	2	10.25	5
Eggs	—	—	—	0.6	0.7
Eye balls	—	—	—	0.21	—
Zooplankton					
Miliamina sp.	—	0.05	—	—	—
Legina sp.	—	—	—	0.06	—
Globigerina sp.	—	—	—	0.06	—
Other foraminifers	0.33	0.25	0.88	—	0.9
Copepods	0.22	—	0.2	—	0.12
Coryceatus catus	0.11	—	—	—	—
Temora tubinata	—	—	—	0.15	—
Phytoplankton					
Navicula sp.	0.11	0.1	0.48	—	0.2
Pleurosigma directum	0.33	—	1	0.75	0.5
Thalassiosira subtilis	—	—	0.08	—	—
Aulacodiscus orbiculatus	—	—	0.08	—	—
Coscinodiscus sp.	—	0.1	—	—	0.2
Nitzschia sp.	0.02	—	—	—	0.02
Rhabdonema mirificum	—	—	—	0.15	—
Tropidoneis lepidoptera	—	—	—	0.15	—
Diploneis sp.	—	0.05	—	0.21	0.15
Triceratium sp.	—	—	—	0.15	0.15
Miscellaneous items					
Mud particles	1.65	5	18	2.22	2
Sand particles	10.7	0.45	5.6	3.3	3
Bottom particles	0.61	0.85	0.8	—	—
Gravels (stones)	1.74	—	—	0.9	0.82
Algal filaments	0.02	0.1	0.08	—	0.1
Sponge spicules	—	0.5	—	—	—
Nematode parasites	0.02	0.05	—	—	—
Net part	0.4	—	—	—	—
Unknown structure	0.44	1	0.2	0.24	3
Semi digested food					
	23.1	50.25	33.2	13.22	7.1

Molluscs—Among the molluscs, trochus opercles, gastropod shell and bivalve shell pieces were observed in all 5 months while *Conus* sp., *Nerita albicilla* and *Turritella cutagulla* were represented in May, August and August respectively.

Fishes—Scales, bones, eye balls and eggs of small fishes were found in small quantities. Among these, fish bones were observed in all 5 months, scales in July to

September, fish eye balls in August and eggs in August and September.

Zooplankton—Zooplankton were mainly represented by foraminifera and copepods. Among foraminifera, *Miliamina* sp. was found in June while *Legina* sp. and *Globigerina* sp. were seen in August.

Phytoplankton—Phytoplankton were represented by 10 species of diatoms in small quantities in different months. Among these, the dominant were *Pleurosigma* sp. and *Navicula* sp.

Among the other items found (Table 1), mud particles, sand particles, unknown structure and semidigested food were observed in all months.

Presence of mud particles, sand particles, gravels and bottom particles in stomach contents of *P. pelagicus* from AD catches shows its bottom feeding habits and sandy-muddy coast dwelling habitats. Occurrence of prawn body parts, crab parts, molluscs, fish parts and plankton predicts its major food items in various months (from May to September).

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Studies on the Pearl Oyster, *Pinctada fucata* (Gould): Seasonal Biochemical Changes

KIRAN DESAI & GAURAV HIRANI
Department of Biosciences
South Gujarat University, Surat 395 007

and

DHIRAJ NIMAVAT
Department of Fisheries
Government of Gujarat, Sikka

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In *P. fucata* glycogen and total lipids are stored during prespawning period (February and November) and they decline in postspawning season (June and December). Proteins increase during the peak gametogenic phase (June to September). The oysters show high values of cholesterol from the onset of gametogenesis in May and also throughout the period of the gametogenesis up to November.

Pearl oyster, *Pinctada fucata* (Gould) of the Gulf of Kutch has not been studied much[1-3], inspite of its economic importance. Some studies have, however, been made on other species of edible oysters of this region[4].

In the present study, monthly variations in glycogen, total lipids, cholesterol, proteins and phosphorous have been estimated in *P. fucata* with a view to correlating the variations with gonadial maturity.

Healthy pearl oysters (100) of 3 to 5 yr age-group were collected in January 1974 from Pirotan, Ajad, Deeda and Moovada islands in the Gulf of Kutch. The oysters were maintained in vertical rafts (20 ft × 15 ft × 15 ft) kept floating in marine pond (200 m^2) with facility for changing sea water every 2 days. The oysters were maintained for 1 yr during which no mortality was recorded.

From January 1975, in the first week of every month, 8 oysters were sacrificed. Part of hepatopancreas and gonad was removed quickly for the estimation of glycogen using Anthrone reagent[5]. Gonad and hepatopancreas of the oysters were stored separately in polythene bags and used for estimating total lipids[6], cholesterol[6] and protein[7]. Phosphorus was estimated by the method of the Fiske and Subba Rao[8].

Total proteins were estimated from nitrogen × 6.25 following Microkjeldahl method.

For all estimations, gonad and hepatopancreas pooled from 8 samples every month were used. Care was taken to see that the oysters sacrificed belong to the same stage of sexual maturity.

P. fucata of the Gulf of Kutch spawns twice a year, from February to April and from November to December, and gametogenesis is observed from May to October[1].

Results (Table 1) show that the gonadial glycogen declines considerably during postspawning period (May and October). Glycogen accumulates in the gonads during onset of next spawning in February and in November. During gametogenesis (May to September), an elevated trend in the gonadial glycogen is recorded as reported earlier[4,9]. Increase in glycogen during active gametogenesis can be attributed to proliferation of sex cells and decrease during spawning to release of gametes from gonads. Decline in the hepatopancreatic glycogen during spawning may be due to utilization of glycogen for gamete formation, as hepatopancreas in molluscs is the storage-site of metabolites[10,11]. Decline in hepatopancreatic glycogen in molluscs during spawning is reported earlier[10,11].

Lipids in the oysters decline during gametogenic activity (June and September) and increase before spawning, (October and February). The decrease may possibly be due to their utilization in gamete production and increase may be a result of the accumulation of gamete, just prior to spawning.

Cholesterol of *P. fucata* decreases during the 2 spawning periods and increases during gametogenesis. Cholesterol being a major component in

Table 1—Monthwise Variation in Glycogen, Lipids, Cholesterol, Proteins, Nitrogen and Phosphorus in *P. fucata*
[Values, expressed in mg/100 g, are mean of 8 samples]

Month	Gonad	Glycogen Hepatopancreas	Lipids	Cholesterol	Nitrogen	Proteins	Phosphorus
				1975			
Feb.	6.3	1.23	5930	5.96	66.2	413.75	470
March	4.5	0.9	6000	6.02	84.23	524.25	1200
April	3.38	2.51	4200	6.26	126	787.5	980
May	0.18	0.43	6400	8.21	86.2	426.25	580
June	0.72	1.41	3600	13.8	120.4	640	1200
July	1.09	1.55	4400	11.8	234	1462.5	1300
Aug.	1.4	1.75	3944	22.2	36	235.3	600
Sept.	1	1.5	1300	40	77	482.3	1000
Oct.	0.72	0.58	2860	39.2	64	400	800
Nov.	3.99	0.52	3980	14	77	482.3	680
Dec.	1.17	0.43	1460	11.2	58.2	363.75	560
				1976			
Jan.	1.88	0.42	1520	33.3	88.4	552.5	260

molluscan sterols[12] is essential in reproduction. It is possible that it is used up during spawning. Fluctuations in cholesterol content of gonads of 4 species of edible oysters of the Gulf of Kutch during spawning and gametogenic activity have been reported[4].

Total proteins increase initially during gametogenesis (June, July) and fall as the gametogenic activity advances (August to November).

Total phosphorous declines during 2 spawning seasons; however, it increases in peak of active gametogenesis, June-July. In the postspawning, it decreases again. The decrease during spawning may be due to the estrusion of gametes. Decrease in phosphorus has also been reported in other species of oysters[4].

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Distribution, Characters & Habits of *Clypeomorus clypeomorus* Jousseaume (Gastropoda: Cerithiidae) of the Visakhapatnam Coast

L MANMADHA RAO & D V RAMA SARMA
Department of Zoology, Andhra University
Waltair 530 003

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Distribution and density of *C. clypeomorus* at different stations on the Visakhapatnam coast and at different tide levels are reported. The characters of the shell, operculum, jaws, radula and foot are given. The moving habits of the snail and the organisms associated with *C. clypeomorus* are described.

Information on the hornsnail, *Clypeomorus clypeomorus* of the family Cerithiidae is scanty. The 4 species of *Clypeomorus* reported are from the Great Barrier Reef[1]. *C. clypeomorus* occurs in great abundance among the shingles of Visakhapatnam coast. It closely resembles in its characters the genus *Cerithium* which is also a member of the family cerithiidae. During the earlier stages of the work the present snail has been identified as *Cerithium morus* following the description provided by earlier workers[2,3]. Subsequently some other snails have also been encountered in the same area and are tentatively identified as *Cerithium clypeomorus, Cerithium splendens* and *Cerithium obeliscus.*

While working on the larval development of this snail conspicuous differences were noted with regard to size of the egg capsule, spawning period, number of eggs per spawn, size of the veliger and life span of the veliger stage. These differences raised doubts as to the correct identity of the snail under study. Re-examination of the material revealed the existence of changes in the shape of the shell, aperture and sculpture of the shell. The shells were examined by Dr Houbrick of the Smithsonian Institution. He identified what was identified earlier as *Cerithium obeliscus* as *Rhinoclavis sinensis* and the snails *Cerithium morus, C. clypeomorus, C. splendens* (identified so by us) as *Clypeomorus* sp. Houbrick cautioned "Cerithiids exhibit much polymorphism in shell colour, sculpture and size. Because of the high variation within each species they have been split up by previous workers and considerable synonymy exists"[4].

While studying the larval development of *C. clypeomorus* many conspicuous differences were observed between the developmental stages of the present snail and those of *Cerithium morus*[5-7]. These differences should be considered in identifying this snail. Therefore, the present snail, *C. clypeomorus* differs significantly in the developmental features from the other cerithiids occurring in the country.

Observations were made at 3 stations, viz. stations I and II at Waltair point and station III at Rishikonda lying between the lat. 17°40′30″ and 17°45′ N and the long. 83°16′15″ and 83°21′30″E on the east coast of India, at weekly intervals. Detailed observations were, however, made at Waltair point shingles. Tidal levels and their vertical ranges on the Visakhapatnam coast were earlier described[8].

Collections were made at 3 tidal levels, i.e. Mean Sea Level (MSL), Mean Low Water Neaps (MLWN) and Mean Low Water Springs (MLWS). Detailed observations were made on the snails collected at the mid water zone (around MLWN). Population density was estimated in each station at 9 different places, selected at random, and the average number of animals from these different places is given as population density per m^2 area at each station. The density of the population at different tide levels was also estimated by the same method.

The moving habits of the snail were observed in the field by marking the animal with enamel paint during low tides. The point of release was also marked with the same paint. During successive low tides the distance travelled by the animal was measured along straight lines from the point of release.

The animals associated with *C. clypeomorus* were collected and identified. The animals that settled on the shell were collected by rinsing the freshly collected snails in sea water. The serpulids living on the shells were collected by carefully cutting open their tubes. They were later fixed in 5% formaldehyde and identified. The structure of the radula was studied by removing it from the buccal mass and spreading it on a white background.

Distribution—The snails prefer protected locations such as the under surfaces of small stones, pebbles and boulders and adhere in clusters to the substratum with the foot. The animals are generally absent on areas directly exposed to wave action. In some instances the animals are found burried in the sand in between the rocks. This is perhaps due to the dislodging of the animals by wave action. The animals occur only in shingles. They are not observed in places where the rocks are big in size. The snails are mostly confined to the region around MLWN and seldom present below MLWS and above MHWN. Young snails are most abundant in between MSL and MLWN (Fig. 1).

Density—Comparatively more animals are present at stations I and II, the bulk of which being mature individuals. The average number (range in parenthesis) of animals per m^2 are 1160 (340-2248), 955 (280-2208) and 763 (230-1650) respectively in stations I, II and III. At all the 3 stations the population density is more around the MLWN level (Table 1). The percentage frequency of different size group animals at the same tide level and the percentage frequency of same size group animals at different tide levels are given in Fig.2.

Characters—Shell: The shell is conical in shape (Fig. 3). The surface is rough with strongly raised spiral ridges of small tubercles which are spread transversely. The spire is pointed and the protoconch is generally worn out. A deeply excavated short anterior canal and an ill developed posterior canal are present. Callus formation is considerable both on the outer and inner lips. The shape of the aperture varies from oval to that of the letter 'D'. The body whorl of the shell contains 6 spiral rows of tubercles. Other whorls of the shell contain 3 rows, the tubercles of the distal 2 rows are more prominent than the proximal row. The colour of the shell is dark grey to black. Some of the shells are worn out due to the wave action and turned whitish

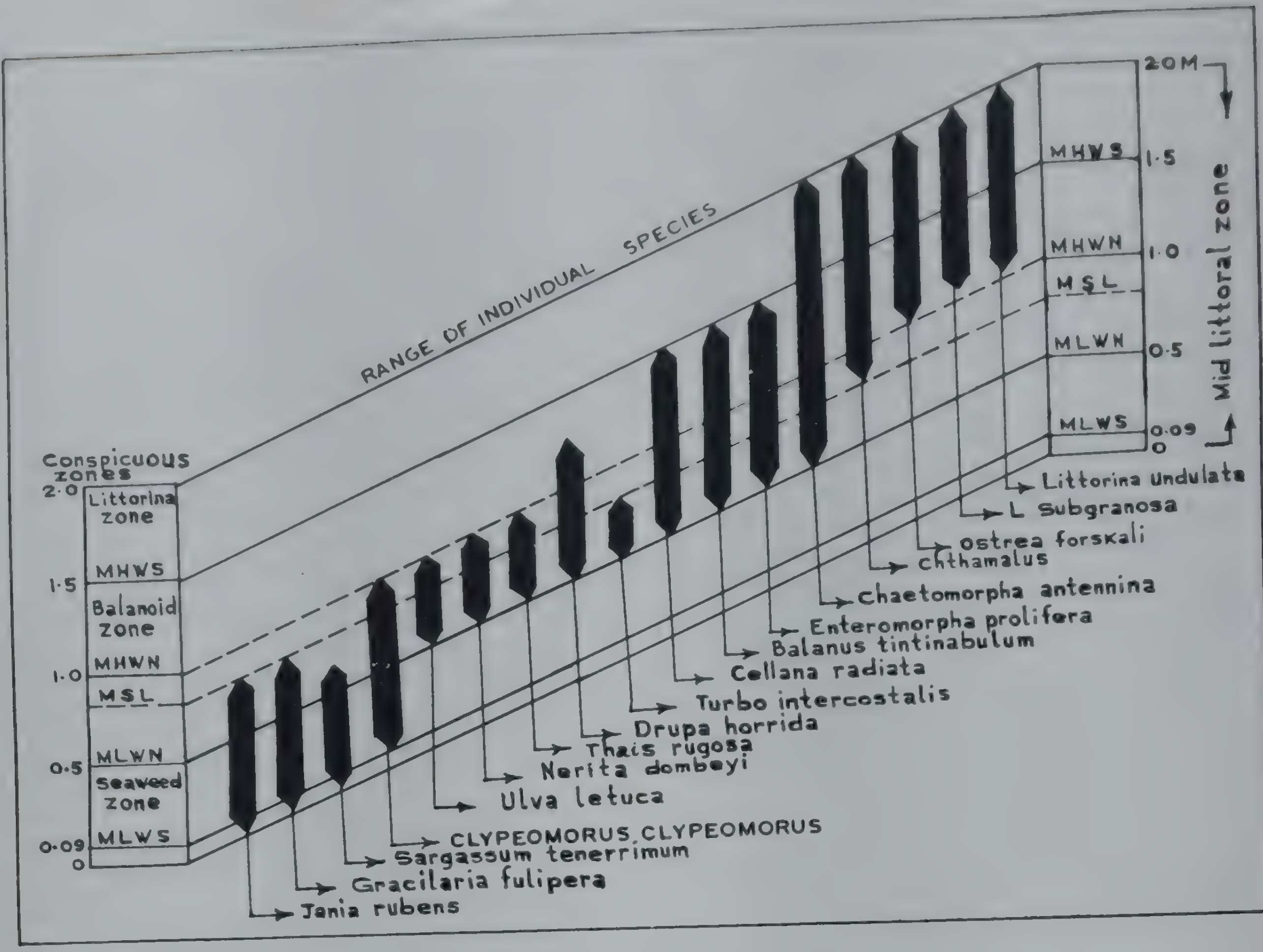
RANGE OF INDIVIDUAL SPECIES
Conspicuous zones
2.0
Littorina zone
MHWS
1.5
Balanoid zone
MHWN
1.0
MSL
MLWN
0.5
Seaweed zone
MLWS
0.09
0
20M
MHWS 1.5
MHWN 1.0
MSL
MLWN 0.5
MLWS 0.09
0
Mid littoral zone
Littorina undulata
L subgranosa
ostrea forskali
chthamalus
chaetomorpha antennina
Enteromorpha prolifera
Balanus tintinabulum
Cellana radiata
Turbo intercostalis
Drupa horrida
Thais rugosa
Nerita dombeyi
Ulva letuca
CLYPEOMORUS CLYPEOMORUS
Sargassum tenerrimum
Gracilaria fulipera
Jania rubens

Fig. 1—Zonation at Waltair point

Table 1—Density of the Population at Different Tide Levels

Tide level	Density/m^2		
	Station I	Station II	Station III
MSL	595	370	332
MLWN	2037	1954	1451
MLWS	852	540	506

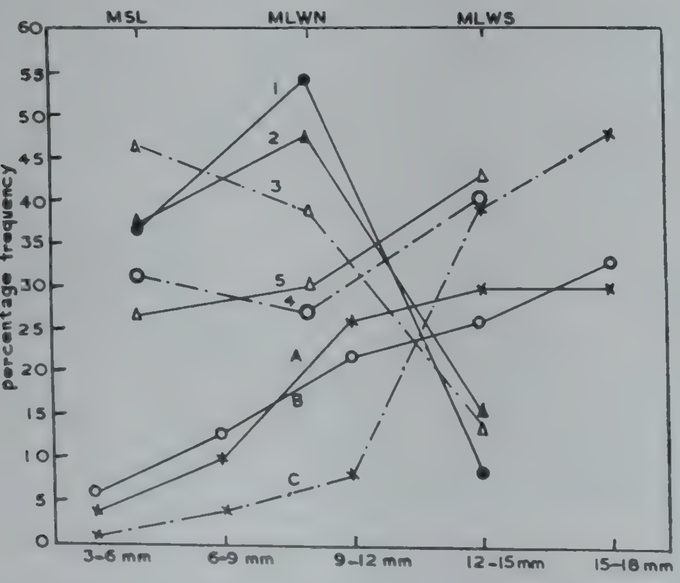

Fig. 2—Percentage frequency of different size groups at same tide level and same size group at different tide levels [Size groups (mm): 1, 3 to 6; 2, 6 to 9; 3, 9 to 12; 4, 12 to 15; and 5, 15 to 18. Tide levels: A, MSL; B, MLWN; and C, MLWS]

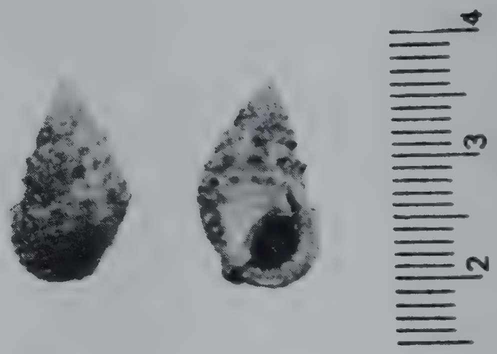

Fig. 3—Shell of *C. clypeomorus*

brown. The maximum size of the shell is 18 mm. The operculum is oval and horny with an eccentric nucleus. It measures about 6 mm in width.

Jaws and radula: A pair of tan coloured jaws are present on the roof of the buccal mass. The 2 jaws are united dorsally by cuticle. Each jaw is roughly triangular in shape and to some extent elongated. The radula is narrow (5 to 6 mm length and 0.5 to 0.6 mm width). It is a typical taenioglossate type of radula and closely resembles that of the allied genus *Cerithium*. There are about 85 to 100 rows of teeth.

Foot: The foot is relatively small and the maximum size is 6 mm in the adults. The shape of the foot at rest is roughly triangular but during locomotion it is observed that the anterior half of the foot first elongates and gets fixed to the substratum and then the posterior portion is released and drawn towards the anterior portion. The colour of the foot is dark grey on the dorsal surface and pale grey on the ventral surface. The sole is provided with subepithelial gland cells secreting mucus. No grooves are discernible in the foot.

Moving habits—During the high tide the shingle beds are totally submerged and the wave action is considerably strong and hence their movements and feeding could not be observed. However, observations are made sometimes with difficulty at the MHWN level during the hightide. Small stones submerged in water during high tide are lifted and observed. The animals are present in clusters underneath the stones and pebbles. Sometimes animals are also found accidentally burried in the sand among the shingles.

When the tide recedes they slowly move about grazing on the algae or detritus present on the surface of the stones and pebbles. They seem to exhibit positive phototaxis because at times of low tide these animals get spread over the upper surfaces of the stones and boulders of the midlittoral zone in the intertidal region basking in the sun.

Although the animal is slow moving it covers fairly extensive areas in search of food and shelter. Twenty animals each from MHWN level and MLWN level were painted and released at the commencement of high tide. The animals were observed for their movements on the next day at the fag end of the low tide. The animals (6) at MHWN level move 46 cm in one day compared to those (9) at MLWN (34cm).

Associated organisms—Shells of *C. clypeomorus* provide substratum to some organisms and the most common among them being serpulids, *Pomatoleios crosslandi* and *Hydroides brachyacantha*. In the order of abundance comes the egg capsules of different species of *Nerita*. The barnacle *Chthamalus* also grows on the shells of these snails. Besides these, the bivalve mollusc *Gastrochaena impressa*, the barnacle *Balanus amphitrite* and some calcareous algae also settle on the shells of these snails.

The authors thank the CSIR for awarding J.R.F. to one of them (L.M.R.). Thanks are due to Prof K Hanumantha Rao, Head of the Department, for his interest and to the authorities of the Andhra University for facilities.

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Seasonal Variations in Glycogen of Some Marine Fishes of Saurashtra Coast

A P MANSURI

Biosciences Department, Saurashtra University, Rajkot (Gujarat)

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Glycogen content was estimated in different muscles of 4 commercially important marine fishes *Johnius vogleri* (Bkr), *Megalaspis cordyla* (L.), *Arius maculatus* (Thunberg) and *Ilisha megaloptera* (Swainson), of Saurashtra coast for 12 months. Well marked seasonal variations were observed in the level of glycogen; high level was noticed mostly during August to October. Seasonal glycogen changes appear to be influenced by maturation cycle and depletion (spent stage) of gonad.

Biochemical analyses of muscles (edible parts) of fish for fat, glycogen, proteins, lopolytic and glyocolytic enzymes, vitamins, etc. have been done in several marine and fresh water fish to realise their food and nutritional value[1,2].

In spite of the fact that more than 75 species of edible fishes are captured from the vast coastline of Gujarat (1063 km), practically no detailed biochemical analysis of the fish has been carried out. Recently, Bhavsar[3] and Verghese[4] have done biochemical analysis of body muscle, liver and gonad in pomfrets (*Pampus argenteus* and *Parastromateus niger*) and mudskippers (*Periophthalmus dipus* and *Boleophthalmus dentatus*) respectively of Saurashtra coast. Therefore, in the present study, glycogen content of some commercially important marine fishes of Saurashtra coast has been estimated.

The fishes (scientific names and family name in parenthesis) studied are: Dhoma [*Johnius vogleri* (Bkr); Sciaenidae], Bangara [*Megalaspis cordyla* (L); Carangidae], Khangi [*Arius maculatus* (Thunberg); Ariidae] and Kanti [*Ilisha megaloptera* (Swainson); Clupeidae].

Monthly collections of fishes for 1 yr (1977) were made from the trawlers and gill nets fishing off Saurashtra coast with bases at Porbander/Veraval. The freshly collected fishes were dissected, different muscles removed carefully, and small pieces (500 mg) of respective muscle transferred to test-tubes containing 30% KOH. The test-tubes were brought to the laboratory and glycogen estimated by the method of Seifter *et al.*[5]. All the estimations were made in triplicate and values pooled.

Table 1—Seasonal Variations in Glycogen Content (μg/g fresh weight) of Different Muscles of Some Commercially Important Fishes of Saurashtra Coast

Muscle	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
						Johnius vogleri						
1	80	100	105	110	115	112	130	310	150	120	112	60
2	60	80	90	100	103	124	160	300	290	130	116	124
3	80	100	110	95	110	188	170	150	230	160	40	60
4	90	110	108	110	118	139	190	230	350	180	125	100
5	80	90	90	95	108	120	110	230	380	80	70	110
6	100	120	110	115	120	80	130	320	270	450	130	113
7	100	130	110	120	125	112	160	390	330	250	120	118
						Megalaspis cordyla						
1	40	80	90	95	98	80	100	144	140	130	40	80
2	60	90	100	105	110	90	80	156	147	80	60	103
3	40	80	85	90	108	118	120	184	142	119	130	108
4	114	100	104	115	118	127	160	360	240	100	123	100
5	110	110	109	112	120	118	200	550	390	130	156	107
6	90	120	110	122	128	125	140	260	395	120	123	110
7	113	110	115	123	130	135	200	340	330	100	112	102
						Arius maculatus						
1	100	90	94	100	105	115	118	116	360	150	101	70
2	90	110	112	115	121	126	119	110	260	170	110	80
3	120	118	120	118	125	125	124	128	370	190	80	100
4	90	110	109	115	120	125	117	150	270	160	102	110
5	110	100	108	113	118	114	118	140	350	320	105	103
6	100	80	90	100	98	112	119	118	127	280	200	100
7	100	120	119	125	128	131	130	128	370	235	180	120
						Ilisha megaloptera						
1	100	90	93	98	110	109	120	230	350	117	103	80
2	90	100	110	109	112	115	117	135	350	330	118	105
3	—	—	—	—	—	—	—	—	—	—	—	—
4	—	—	—	—	—	—	—	—	—	—	—	—
5	110	100	112	118	120	140	210	418	430	116	118	109
6	110	120	125	121	130	135	260	520	360	141	120	80
7	140	160	155	165	163	168	280	440	320	250	138	108

Numbers 1 to 7 represent the following muscles: Pectoral fin—1, adductor muscle and 2, abductor muscle; Pelvic fin—3, adductor muscle and 4, abductor muscle; Caudal fin—5, superficial flexor muscle and 6, deep flexor muscle; and Lateral-line muscles—7, lateral muscle

Glycogen content in various fin muscles and lateral-line muscles of different fishes are given in Table 1. Higher glycogen content is observed in the muscles of *I. megaloptera*, in almost all months of the year. Distinct variations in glycogen content are noted during August to December in all the 4 fishes. A noticeable increase in glycogen content of different muscles of *J. vogleri* and *M. cordyla* is observed during August to October. Similarly, a high level of glycogen in various muscles is recorded during July to October in *A. maculatus* and during August to October in *I. megaloptera*. It is seen from the results that seasonal cycle of glycogen seems to be influenced by maturation cycle and depletion (spent stage) of gonad. This has also been reported by Bhavsar[3] and Verghese[4]. Maximum level of glycogen content is recorded during the period when the fish was gravid and almost ready to spawn, i.e. from August to November, in most of the fishes studied. Similar observations are made about glycogen in muscles and liver of mudskippers[3]. Depletion in muscle glycogen of fishes during spawning observed in the present study, may be for their extensive locomotion during spawning season. During recovery period of gonad, i.e. from March to June, a gradual increase in glycogen content of different muscles is observed in all species.

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Cellular Composition of Blood of Marine Teleost, *Gerres filamentosus*(Cuvier), from Visakhapatnam Harbour

K USHA RANI & K SRINIVASA RAO

Department of Zoology
Andhra University, Waltair 530 003

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Cytomorphology of immature, mature, and senile erythrocytes and leucocytes of *G. filamentosus* has been studied using Giemsa stained smears. The blood contains nucleated erythrocytes and leucocytes which include non-granulocyte lymphocytes (59.45%), thrombocytes (28.2%), monocytes (4.6%), macrophages (0.3%), and all the 3 types of granulocytes (7.45%), viz. neutrophils, eosinophils, and basophils. Abnormally high percentage of immature erythrocytes and leucocytes, observed in samples collected in March 1977, may be due to environmental stress or pollution. Polymorphy of thrombocytes and phagocytic activity of macrophage cell are noteworthy features. Cytometric measurements of various cell types are made to calculate the nucleo-cytoplasmic (N/C) ratio.

Haematology of fishes gained recognition in the diagnosis of fish diseases. Composition of blood of fishes is under greater influence of environmental factors compared to terrestrial warm blooded animals and haematological changes due to environmental pollution are of interest. Though information is available on the blood of several fishes[1-14], detailed information on the haematology of fishes from India is very scanty[15].

Differential counts and cytomorphology of blood cells are studied in *Gerres filamentosus* from Visakhapatnam harbour, which is affected by industrial effluents and organic pollution in the form of untreated domestic sewage[16].

Blood from the fish was collected by cardiac puncture with the help of a heparinized syringe in the field. As the fish were of small size (7-10 cm), inadequacy of the blood samples restricted their use to the study of blood smears only. The air dried smears were fixed in methanol for 5 min and then stained by Giemsa's stain using pH 7.2 phosphate buffer. Differential counts and cytometric measurements of cytosome and nucleus of various cell types were made in the laboratory. From the cytometric measurements the nucleo-cytoplasmic (N/C) ratio of the blood cells which is related to their oxygen carrying capacity, was calculated.

Description of cell types is based on a combination of terms used by earlier workers[6-11, 14,15]. The principal cellular components of the blood of *G. filamentosus* are the non-nucleated erythrocytes, thrombocytes, lymphocytes, monocytes, macrophages and the granulocytes like neutrophils, eosinophils and basophils. Also, several developing and degenerating stages, mainly of the erythrocytes, are seen in some smears.

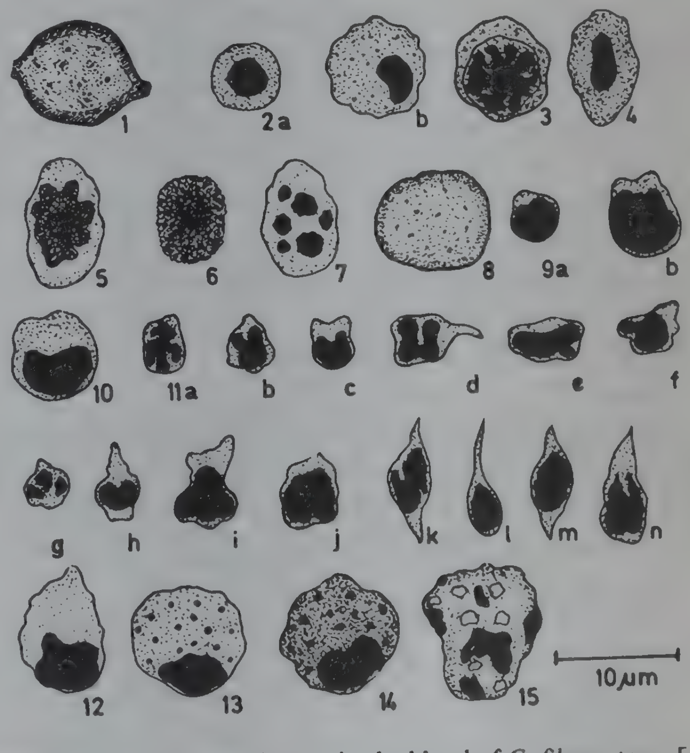
Haemoblasts—It is a large agranular cell containing a large purplish stained nucleus which has uniform reticular pattern. The basophilic cytosome shows pseudopodia (Fig. 1). These cells are absent in the peripheral blood smears except in those of March 1977 samples, and they constitute 0.5% of all the erythrocytes.

Prolymphocytes—These cells (1%) are seen in the smears of March samples only. They are more or less round, having a round or indented nucleus (Fig. 2a). The clear blue staining of the cytosome and the dark violet of the nucleus is similar to that of the mature lymphocytes.

Progranulocytes—They constitute 0.5% of all the erythrocytes and seen only in the smears of March sample. They are more or less spheroid in nature with a kidney shaped, small, eccentric, nucleus. Cytoplasm stains light bluish, and the nucleus stains pinkish violet (Fig. 2b). This is the precursor cell of all the granulocytes.

Erythrocyte series—Cytometric measurements and N/C ratios of various cell types are given in Table 1.

Immature erythrocytes—These are variously known as normoblasts or erythroblasts. As a group these cells constitute normally about 2% of the erythrocytes. Their composition is somewhat abnormal in the March sample.



Figs 1 to 15—Various cell types in the blood of *G. filamentosus* [1 Haemoblast. 2—a, Prolymphocyte; b, progranulocyte. 3 Basophilic Normoblast (BN). 4 Mature erythrocyte. 5 Disintegrated erythrocyte. 6 Disintegrated erythrocyte showing only a 'nuclear shadow'. 7 Senile erythrocyte showing 'exploded nuclei'. 8 Enucleate erythrocyte. 9—a, Small lymphocyte; b, large lymphocyte. 10 Monocyte. 11—a-f, Maturing thrombocytes; g, senile thrombocyte; h-n, mature thrombocytes. 12 Neutrophil. 13 Eosinophil. 14 Basophil. 15 Macrophage.]

Table 1—Cytometric Measurements of Various Cellular Elements of the Peripheral Blood of *G. filamentosus*

Cell type	Cytometric measurements		N/C ratio $\frac{L \times W \text{ of nucleus}}{L \times W \text{ of cytosome}}$
	Cytosome(C) L × W(μm)	Nucleus(N) L × W(μm)	
	Erythrocyte Series		
Mature erythrocyte	9.51 × 5.51	3.40 × 2.42	0.157
Basophilic normoblast	8.35 × 8	8.00 × 7	0.833
Polychromatocyte	8.35 × 8	8.00 × 7	0.833
	Leucocyte Series		
Small lymphocyte	3.65 × 3.65	3.65 × 3.65	1
Large lymphocyte	6.18 × 6.18	6.18 × 5.51	0.892
Small thrombocyte	5.00 × 5	5.00 × 4.34	0.868
Large thrombocyte	8.35 × 5	5.00 × 5	0.598
Monocyte	5.85 × 5.85	5.00 × 4.18	0.614
Macrophage	9.60 × 6.68	—	—
Neutrophil	8.35 × 6.68	5.00 × 4.18	0.376
Eosinophil	8.35 × 8.35	4.18 × 3.34	0.2
Basophil	8.35 × 7.51	5.00 × 4.18	0.335

L= Length; W= Width

The basophilic normoblasts are either roundish or elliptical with a prominent purplish-pink stained nucleus, which is also roundish occupying most of the intensely basophilic cytosome (Fig. 3). The chromatin has cart-wheel shaped arrangement in the nucleus. In the March sample they form 3% of all the erythrocytes.

Cytosome of polychromatocytes is light bluish with centrally placed pinkish stained nucleus with radially arranged chromatin. They also form 3% of all the erythrocytes in March sample.

Mature erythrocytes—These cells are mostly ellipsoidal with a centrally placed elliptical nucleus. Cytoplasm stains orange or reddish yellow and the nucleus is dark purple with dense chromatin (Fig. 4). In the peripheral blood smears 98% of the erythrocytes are mature.

In addition to the above types the following are also encountered rather infrequently.

Disintegrated or senile erythrocytes—A few erythrocytes are seen in various stages of disintegration or senility. The disintegrated erythrocytes (Fig. 5) are also called 'basket' or 'smudge' cells. In the advanced stage of degeneration the nuclear membrane is no longer intact and only the pinkish stained nuclear matter (Fig. 6) is visible in the smears. The senile erythrocytes are also formed by the disintegration of nucleus into small or large roundish pieces in the cytoplasm as if the nucleus has 'exploded' (Fig. 7).

Enucleate erythrocytes—They are roundish with a thin outer membrane enclosing pale red cytoplasm which is slightly granular (Fig. 8). These were described as 'ghost cells' by Boyar[17].

Leucocyte series—Of all the leucocytes nongranular lymphocytes form the major component (59.45%). The other nongranulocytes are (Table 2) thrombocytes, monocytes and macrophages. The granulocytes are represented by the neutrophils and rarely by the eosinophils and basophils (Table 2). N/C ratios for all the leucocytes are given in Table 1. The morphology of different types is given below.

Lymphocytes—Two different types are distinguished according to size—the small (Fig. 9a) and the large (Fig. 9b) forming 51.25 and 8.2% respectively. The shapes and staining characteristics of these cell types are very similar to that of other teleosts[8].

Monocytes—These are similar in size to the larger lymphocytes but the nucleus, which is small, is either bean shaped or kidney shaped and stains pinkish-violet. it is placed eccentrically in the basophilic cytoplasm (Fig. 10).

Thrombocytes—In accordance with the preference shown by earlier workers[8,18], these are included under the leucocytes in the present study. These are functionally equivalent to mammalian blood platelets. Their nuclei may vary greatly in shape. In the same individual and at the same time, they may be round, oval, bilobed or horse shoe shaped. The nucleus stains dark violet or dense purple in mature forms where the clear blue cytosome is either tongue shaped or pointed at one end or both ends (Figs. 11h-n). In the immature or maturing thrombocytes the cytoplasmic content is very little as in small lymphocytes (Figs. 11a-f). Occasionally senile thrombocytes are also seen (Fig. 11g).

Neutrophils—These are the most prominent of all the granulocyte leucocytes constituting about 6.7% of all the leucocytes. They may be called fine

Table 2—Comparison of Differential Count (percentage) of Leucocytes in *G. filamentosus* and *G. cinereus*

Cell type	*G. filamentosus* (Present study)	*G. cinereus* (Saunders[8])
Large haemoblasts	—	0.1
Small haemoblasts	—	1.1
Small lymphocytes	51.25	35.2
Large lymphocytes	8.2	1.1
Thrombocytes	28.2	54.9
Monocytes	4.6	—
Macrophages	0.3	0.3
Neutrophils	6.7	7
Eosinophils	0.55	0.3
Basophils	0.2	—

granulocytes, but no prominent granules are seen in the present study. The nucleus is usually eccentric, sac like (Fig. 12) and consists of purple staining chromatin, in the delicate grayish blue cytosome.

Eosinophils—These are coarse granulocytes forming about 0.55% of all the leucocytes and are rare in occurrence. The cells are more or less spherical with bluish cytoplasm containing a few purplish orange specific granules. Nucleus is purplish and either bean shaped or spheroid, placed eccentrically in the cytosome (Fig. 13).

Basophils—These are other variety of coarse granulocytes and form only 0.2% of all the leucocytes. Cells are more or less circular in outline with a kidney shaped dark violet nucleus placed eccentrically in the pinkish cytoplasm showing clear blue basophilic granulations allover (Fig. 14).

Macrophages—These are the largest of all the leucocytes, but rare (0.3% only) in their occurrence. Cytosome is mostly basophilic with pseudopodial extensions and contains many delicate blue vacuoles and erythrocyte remains (Fig. 15) suggesting phagocytic activity. No distinct nucleus is present.

Lymphocytes (59.45%) form the major component of all the leucocytes in the blood of *G.filamentosus.* Differential counts of *G. cinereus* (Table 2) show high percentage of thrombocytes. Marked difference between the 2 species of *Gerres* lies in the percentage composition of small lymphocytes and thrombocytes. The former is more in *G. filamentosus* while the latter is more in *G. cinereus.* The difference is perhaps either due to geographical location or environmental conditions. Also the monocytes and basophils are not reported in *G. cinereus.* But the percentage of macrophages neutrophils and eosinophils are more or less similar in both.

The large (0.1%) and small haemoblasts (1.1%), reported in the blood of *G. cinereus*, are not common to all blood smears of *G. filamentosus*, but are seen in March samples only.

Deviations from the normal composition of the blood cells are not uncommon under conditions of disease or any other kind of physiological stress. Presence of basophilic normoblasts has been reported in diseased fingerlings and yolk sac fry of silver salmon, *Oncorhynchus kisutch*[2,3] as well as *O. nerka*[19]. These basophilic normoblasts (3%) are observed in the present study also in March samples along with other immature cell types such as haemoblasts (0.5%), polychromatocytes (3%), prolymphocytcs (1%) and progranulocytes (0.5%). The presence of progranulocytes and prolymphocytes was reported to be of pathological significance[11].

In the present study the abnormality observed in the form of high percentage of immature cells in March is not due to disease as there is no such manifestation on the fishes examined. It is, however, possible that it may be the result of changing conditions in the harbour waters in March like a marked rise (to as high as 36°C) in the surface temperature within the shallow creeks adjoining the north arm of the harbour from which the fish have been collected. This would adversely affect the percentage saturation of dissolved oxygen. Detailed hydrographical and biological observations[20] indicate that dissolved oxygen fluctuates diurnally in the harbour waters (0 to 20 mg/litre) and the accumulated organic matter imposes additional stress on fishes particularly during the summer months (March-June) when the rate of decomposition through bacterial action is high.

A definite relationship between changes in environment and variations in the blood counts was already reported[21].

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Distribution of Trace Elements in the Leaves of Mangroves

LEELA J. BHOSALE
Department of Botany, Shivaji University
Kolhapur 416004

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Five trace elements from the leaves of 9 mangroves [*Rhizophora mucronata* Lamk; *Bruguiera gymnorrhiza* Lamk; *Ceriops tagal* Perr, C.B. Rob; *Avicennia officinalis* L.; *Lumnitzera racemosa* Willd; *Aegiceras corniculatum* (L.) Blanco; *Acanthus ilicifolius* L.; *Aeluropus lagopoides* L.; and *Clerodendron inerme* L.] are estimated. Manganese is comparatively more while the quantities of zinc and molybdenum, in many cases, are very near. Cobalt is in lowest amount. It is suggested that the range of variation in the levels of trace elements is more because of the specificity of the plant for a particular element rather than the response of plant to edaphic factors.

There is very little data available on trace elements in mangroves. The present paper reports quantitative distribution of cobalt, manganese, molybdenum, copper and zinc in some mangroves.

The leaves of 9 species of mangroves collected from Ganapatipule (17°9′ north and 73°2′ east) were washed and oven-dried. Trace elements were estimated by emission spectroscopy (Spectroscopy Division, BARC, Bombay) employing the method of Dixit *et al.*[1]

Cobalt is lowest (1.4 μg/g dry weight) in *Aeluropus* and highest (5.9 μg/g dry weight) in *Lumnitzera* (Table 1). Similarly, variation in manganese is also wide. The levels of Zn^{2+} in the present investigation are similar to those reported by Walsh[2], while Co^{2+} levels are comparatively low. Morton[3] has reported Co^{2+}, Mn^{2+} and Zn^{2+} from the leaves of *Rhizophora mangle*. His values are very high for Co^{2+} and Zn^{2+} (52 and 43 μg/g dry weight respectively). In case of *R. mucronata* at Ganapatipule the levels are 2.3 and 11.5 μg/g dry weight for Co^{2+} and Zn^{2+} respectively.

Table 1—Distribution of Trace Elements in the Leaves of Mangroves

[Values are expressed as μg/g dry weight]

Species	Co	Mn	Mo	Cu	Zn
Rhizophora mucronata	2.3	32.2	11.5	4.1	11.5
Bruguiera gymnorrhiza	2.3	46.5	11.6	6	12.8
Ceriops tagal	2.2	82.2	11.1	5.3	11.1
Avicennia officinalis	3.2	158.7	15.9	9.2	17.5
Lumnitzera racemosa	5.9	29.4	29.4	4.1	29.4
Aegiceras corniculatum	1.7	25.8	8.3	4.3	8.3
Acanthus ilicifolius	3.3	96.7	16.7	9	24.7
Aeluropus lagopoides	1.4	54.3	7.1	6.6	107.1
Clerodendron inerme	3.2	133.3	15.9	10.8	36.5

Ramadas *et al.*[4], who investigated Mo^{2+} and Mn^{2+} from mangrove ecosystem of South India, have stated that the trace elements, including iron, have stimulatory effect on primary production of the ecosystem. Possibly, the 5 trace elements found in the leaves of mangroves at Ganapatipule have a role in productivity of mangroves.

It is interesting to note that the members of family Rhizophoraceae have very close levels of trace elements except Mn^{2+}. In fact their distribution in the ecosystem is quite different. *R. mucronata* is found at seaward fringe, *Ceriops tagal* in the mixed mangrove stand and *Bruguiera gymnorrhiza* at landward fringe. *Avicennia officinalis* is found very close to *R. mucronata* in the ecosystem at Ganapatipule, but it differs much in levels of trace elements from the latter. *Lumnitzera racemosa*, *Aegiceras corniculatum*, *Aeluropus lagopoides* and *Acanthus ilicifolius* occur in a common association, bordered with *Clerodendron inerme*. However, there is no correlation of values of trace elements in these plants. It appears that supporting soil of these plants, which may be different with respect to sedimentation types[5] has little effect on uptake of these elements.

Lumnitzera has highest cobalt value which may have relation with vitamin B_{12} coenzymes and indirectly nitrogen metabolism, or may be more needed as a cofactor. Zn and Cu also serve as cofactors. Mo is attached to some proteins thereby forming metalloenzymes. Mn in some cases, replaces Mg. It is the activator of phosphate transferring enzymes as well as enzymes of TCA cycle. Adequate values recorded for trace elements in higher plants[6] indicate that cobalt is comparatively less in mangroves, except in *Lumnitzera*, the adequate amount being 6 μg/g dry weight. However, Mo is very high (0.1 μg/g dry weight). Mn in normal amounts must be 50 μg/g whereas mangroves show the range from 25.8 to 158.7 μg/g dry weight. This is possibly because some plants absorb it more and may use in place of Mg. Similar is the case with Zn, which is sufficient in quantities of 20 μg/g dry weight. However, present results show greater range from 8.3 to 107.1 μg/g dry weight. Range for Cu is not very wide. It can be concluded that the range of variation in the levels of trace elements is more because of specificity of the plant for a particular element rather than the response of plants to edaphic factors.

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Wave Conditions & Wave-induced Longshore Currents in the Nearshore Zone Off Krishnapatnam—B.S.R. Reddy, G. Venkata Reddy & N. Durga Prasad, Department of Meteorology & Oceanography, Andhra University, Waltair 530003

Wave Characteristics Off Paradip Port—R. Varadarajulu, Department of Meteorology & Oceanography and M. Hari Krishna, Department of Geography, Andhra University, Waltair 530003

Hydrographic Characteristics & Tidal Prism at the Cochin Harbour Mouth—V.S. Rama Raju, P. Udaya Varma & Abraham Pylee, National Institute of Oceanography, Research Centre, Cochin 682018

Seasonal Variations in Hydrographic Conditions of Estuarine & Oceanic Waters Adjoining the Old Mangalore Port—M.P.M. Reddy, V. Hariharan & N.P. Kurian, University of Agricultural Sciences, College of Fisheries, Mangalore 575002

Coccoliths from Sediments of the Gulf of Kutch—M.V. Shankaranarayana Guptha, National Institute of Oceanography, Dona Paula, Goa 403004

Succession of Organisms Following Trichodesmium Phenomenon—V.P. Devassy, P.M.A. Bhattathiri & S.Z. Qasim, National Institute of Oceanography, Dona Paula, Goa 403004

Incidence of Red Water Along South Kerala Coast—P. Venugopal, P. Haridas, M. Madhupratap & T.S.S. Rao, National Institute of Oceanography, Regional Centre, Cochin 682018

Food & Feeding Habits of Johnius axillaris (Cuvier) Off Waltair Coast—K. Srinivasa Rao & K.V.S. Janardhana Rao, Department of Zoology, Andhra University, Waltair 530003

Studies on Fungi from Coastal Waters of Bombay & Goa—Joe D'Souza & Albert Araujo, Centre of Postgraduate Instruction and Research (University of Bombay) Panaji, Goa and A. Karande, Naval Chemical and Metallurgical Laboratory, Tiger Gate, Bombay 400001 and Y.M. Freitas, St. Xavier's College, Bombay 400001

Effect of Low Oxygen Concentration on Respiratory Movements of Balanus tintinnabulum tintinnabulum (L)—D.G.V. Prasada Rao & Y. Prabhakara Rao, Department of Zoology, Andhra Unversity, Waltair 530003

Haematology of Ten Pounder, Elops saurus (L), *a Euryhaline Fish from Visakhapatnam Harbour*—K. Usha Rani & K. Srinivasa Rao, Department of Zoology, Andhra University, Waltair 530003

Efficiency of Energy Utilization in the Shrimp, Metapenaeous monoceros Fed on Mangrove Leaves—V. Ramadhas & Sumitra-Vijayaraghavan, National Institute of Oceanography, Dona Paula, Goa 403004

Photosynthetic Pigments in Coastal Ecosystems—A. Panneerselvam, L. Kannan & K. Krishnamurthy, Centre of Advanced Study in Marine Biology, Annamalai University, Parangipettai 608502

Distribution of Organic Matter in Shelf Sediments Off Kakinada, East Coast of India—M. Kalesha, Department of Geology, Andhra University, Waltair 530003

Pisione oerstedii Grube, 1857 (*Polychaeta*: *Pisionidae*) *from the East Coast of India, Bay of Bengal*—N. Siva Rama Sarma & P. Chandra Mohan, Department of Zoology, Andhra University, Waltair 530003

Occurrence of a Podocopan Ostracod Tanella indica sp nov in the Marginal Water Bodies, East Coast of India—C. Annapurna & D.V. Rama Sarma, Department of Zoology, Andhra University, Waltair 530003

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Wave Conditions & Wave-induced Longshore Currents in the Nearshore Zone Off Krishnapatnam

B S R REDDY, G VENKATA REDDY & N DURGA PRASAD
Department of Meteorology & Oceanography, Andhra University, Waltair 530003

Received 5 January 1979

Wave conditions along Krishnapatnam coast (lat. 14°15′N and long. 80°07′E) have been evaluated and discussed. Wave refraction diagrams have been constructed for the average wave conditions and the wave energy distribution along the coast has been critically examined. Longshore currents due to oblique wave approach and due to wave breaker height variations have been computed separately and the character of the resultant currents in the nearshore zone has been established. Stability of the coastal inlet near Krishnapatnam in relation to the currents in the region is also discussed.

Krishnapatnam (lat. 14°15′N, long. 80°07′E) is a minor port situated on the east coast of India in Andhra Pradesh, about 20 km east of Nellore and about 200 km north of Madras. A small river Khandaleru joins the sea here, providing a stable coastal inlet which remains open during all seasons of the year. The Khandaleru river has an extensive catchment area in the hilly regions of southern Andhra and flows through a distance of about 110 km before joining the sea. Near the mouth, the river widens and takes a meandering course. The main flow near the mouth is actually through 2 channels coming from north and south respectively with a shallow island-like feature lying in between the channels. The Khandaleru river with an observed tidal excursion of about 30 km from the mouth forms an excellent backwater which is suitable for the development of a commercial port and a fishing harbour. But at present there is no activity in the Krishnapatnam port due to the bar formation near the mouth. At the entrance the depths are about 1 m below low water while a minimum depth of about 2 m is required for the vessels to enter the port. Further, heavy wave breaking near the mouth over the sand bar prevents even the small fishing boats operating through the entrance. Nevertheless it should be possible to dredge the bar near the mouth and maintain the required depths. But prior to this, it is essential that a thorough study of the character of various marine forces that generate coastal currents and the sediment movement near coast must be undertaken. This paper presents the results of a preliminary investigation on wave climate and associated phenomena along Krishnapatnam coast.

Wave-induced Nearshore Currents

Wave action is the primary source of energy available in the nearshore zone for various processes. Waves change considerably when approaching the shores. The character of the wave changes from a short wave to a long wave and the wave velocity very much depends on the water depth. The waves approaching the shore at an angle in shallow water undergo refraction. The part of the wave in deeper water moves more rapidly than the part in shallow water causing the crest to swing round parallel to the bottom contours. However, this process is not complete nearshore and waves break at a small angle to the shore. This gives rise to movement of water parallel to the shore, termed longshore current. This current especially is responsible for the longshore drift of the sediment on the beach and there is considerable interest in the mechanism of its generation and a number of theories have been proposed[1-6].

For a region with an irregular bottom topography, the wave rays (orthogonals) may sometimes converge or diverge at different points alongshore giving rise to variations in the wave breaker heights along the length of the shore[7].

Wave-induced longshore currents can, therefore, be generated within the nearshore zone by an oblique wave approach to the shoreline or by longshore variations in the wave breaker heights or by combinations thereof. The 2 current generating forces may reinforce or oppose each other depending on the wave refraction pattern for any particular stretch of the coast. Komar[8] has presented an analytical equation that combines the 2 generating mechanisms which will be used later in this paper to calculate the wave-induced longshore currents along Krishnapatnam coast.

Materials and Methods

For the Indian coasts there are hardly any wave recorders that are continually working with the result that there is no recorded wave data for the region under investigation. Hence the wave characteristics (height, period and direction) in deep waters reported by the ships plying in the neighbourhood of Krishnapatnam between latitudes 12°N to 17°N and longitudes 80°E to 85°E for the years 1967 to 1976 have been collected from the records of India Meteorological Department. The wave data have been analysed statistically and the frequencies of their occurrence from 16 directions equally divided from north through east to back are obtained. For each direction the wave heights and periods have been classified into 10 ranges. The average annual distribution of wave heights and periods are presented in Fig. 1.

In any region with the knowledge of deep water wave conditions, the wave characteristics before the wave breaks near the coast can be evaluated by constructing wave refraction diagrams. Wave refraction diagrams have been constructed[9] using the topographic survey charts off Krishnapatnam, published by the Naval Hydrographic survey of India (No. 3007). Wave heights in shallow water for different points along 2 fm line have been calculated using the equation[10]

$$\frac{H}{H_o}=\left[\frac{1}{2}\left(\frac{1}{n}\right)\left(\frac{L_o}{L}\right)\right]^{\frac{1}{2}}\left[\frac{b_o}{b}\right]^{\frac{1}{2}}$$

$$\text{where } n=\tfrac{1}{2}\left[1+\frac{4\pi h/L}{\sinh 4\pi h/L}\right],$$

in which L_0 is the wavelength in deep water; L wave length in shallow water; h depth at the point of investigation; b_0 separation between wave rays in deep water; b separation in shallow water at the point of investigation; H_0 wave height in deepwater and H required wave height in shallow water.

The term $\left[\frac{1}{2}\left(\frac{1}{n}\right)\left(\frac{L_0}{L}\right)\right]^{\frac{1}{2}}$ has constant value along a fixed depth contour while $\left[\frac{b_0}{b}\right]^{\frac{1}{2}}$ varies along a depth contour and is generally referred to as the refraction factor K.

For the breaking waves, wave heights at the point of breaking have been calculated by a different relation[10]

$$\frac{H_b}{H_o}=\frac{1}{3.3\,(H_o/L_o)^{1/3}}\left(\frac{b_o}{b}\right)^{1/3}$$

where H_b is the wave height at the point of breaking. The term $\left(\frac{b_0}{b}\right)^{1/3}$ is the refraction function (K_b) at the point of wave breaking and varies for different points along the coast.

As a result of wave refraction the direction of wave travel changes as the wave approaches the coast. The change in the direction of wave travel at any point is usually given by the direction function α, representing the angle between the wave ray at the point and the coast normal. The α may vary along a depth contour depending on the wave refraction pattern. The wave breaker heights and the α for different points along the coast have been determined as above from the wave refraction diagrams. The longshore currents are then calculated making use of the following relation due to Komar[8]

$$\bar{V}_1=2.7\,u_m \sin\alpha_b \cos\alpha_b-\frac{\pi(2)^{1\;2}}{C_f\,\gamma_b^3}\cdot$$

$$\left[1+\frac{3\,\gamma_b^2}{8}-\frac{\gamma_b^2}{4}\cos^2\alpha_b\right]u_m\,\frac{\partial H_b}{\partial y}$$

where $\bar{V}_1$ is longshore current velocity; u_m maximum value of breaking wave orbital velocity given by $(2\,E_b/\rho h_b)^{\frac{1}{2}}$ in which E_b is the wave breaker energy; h_b is the water depth at breaking and ρ is the density of sea water; α_b direction function at the point of breaking; C_f drag coefficient taken as 0.017 from Longuet-Higgins[4]; γ_b a constant that depends on the deep water wave steepness and on the beach slope. For Krishnapatnam beach a value of 0.8 has been selected from the curves of Longuet-Higgins[4], $\frac{\partial H_b}{\partial y}$ represents the longshore variation in breaker wave heights along the coast.

The term $2.7\,u_m \sin\alpha_b \cos\alpha_b$ in the above equation for $\bar{V}_1$ represents the longshore current generated by an oblique wave approach while the term $\frac{\pi(2)^{1/2}}{C_f\,\gamma_b^3}\left[1+\frac{3\,\gamma_b^2}{8}-\frac{\gamma_b^2}{4}\cos^2\alpha_b\right]u_m\,\frac{\partial H_b}{\partial y}$ represents the longshore current due to variations in the wave breaker heights alongshore. If $\frac{\partial H_b}{\partial y}$ is positive, then the driving forces are opposed to one another and the current is reduced. If $\frac{\partial H_b}{\partial y}$ is negative then the driving forces act together in the same direction and the current generated would be larger than produced by the 2 driving forces acting individually.

Results and Discussion

Wave climate off Krishnapatnam—A large percentage of waves in deepwater are from SW and NE directions (Fig. 1). A relatively small percentage of waves are also observed from SE and E while the waves from W and NW are almost negligible. But the swell from SW or S do not reach Krishnapatnam coast due to the particular orientation of the coast line. The

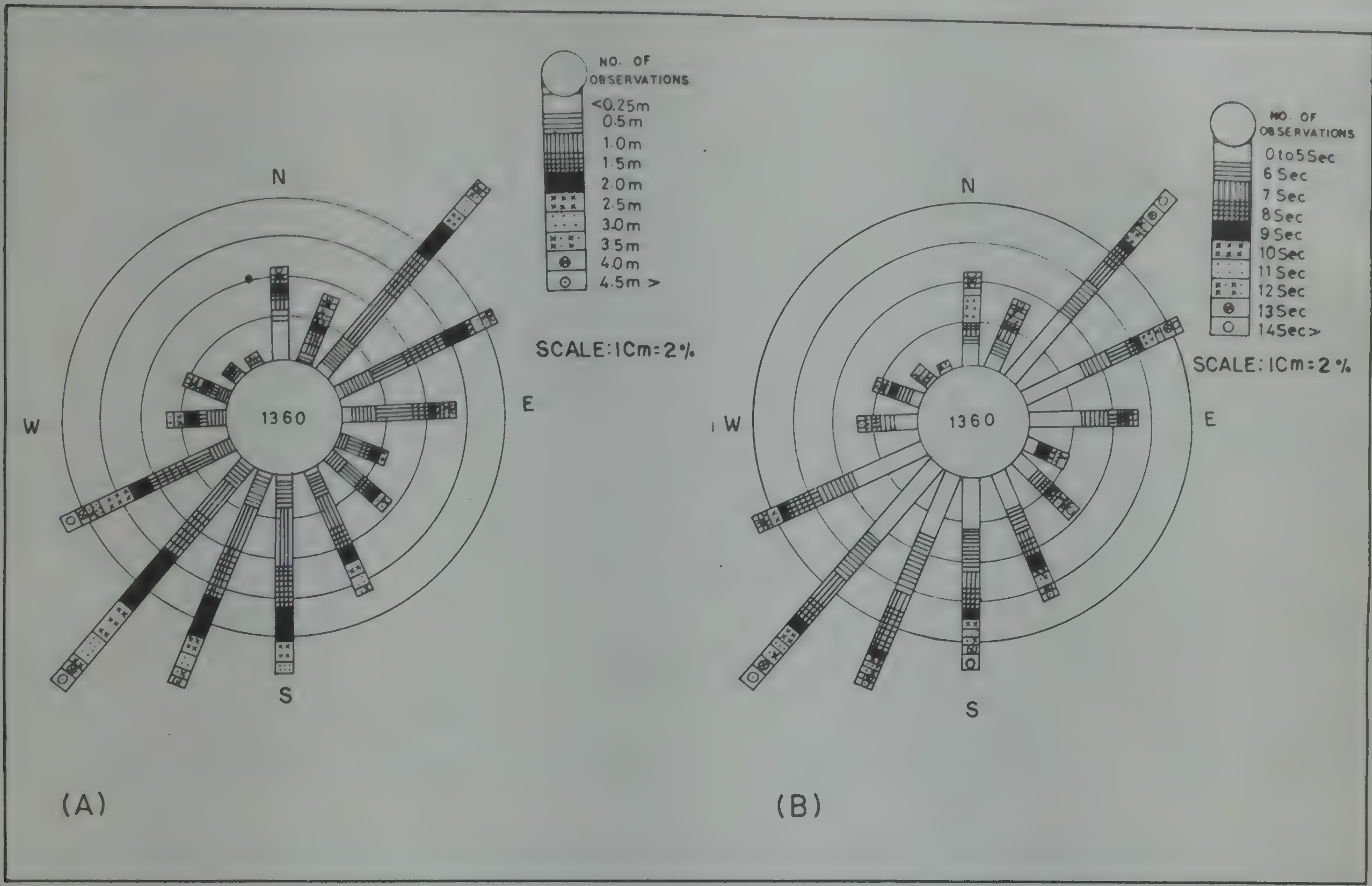


Fig. 1—Average annual wave Rose for (A) wave direction and height and (B) wave direction and period

shores of Krishnapatnam are thus exposed only to the waves coming from NE, E and SE. The wave heights for waves coming from NE, E and SE seem to vary between 0.5 and 2 m on the average, the most frequent wave heights being around 1 m. Exceptionally high waves of the order of 4 m or more also have been recorded but they are very rare and might possibly be related to the cyclones in the Bay of Bengal. The wave periods vary commonly between 5 and 12 sec, the most frequent waves being of 5 sec period. Exceptionally high periods of the order of 14 sec or more are also observed sometimes which again might be related to the cyclones in the Bay of Bengal. The weighted mean of the wave periods is, however, around 7 sec.

Wave refraction and longshore currents—Wave refraction diagrams have been constructed for 7 sec period waves approaching the coast from NE, E and SE. For NE waves [Fig. 2(A)] the wave rays designated as A, B, C, D, ..., start from northeast corner, undergo refraction and terminate near the coast where the waves break. Since the energy between any adjacent wave rays is constant, there is a concentration of energy at points when the wave rays converge, resulting in increased wave heights. The computed wave heights in metres between the successive wave rays are entered in the wave refraction diagrams along 2 fm line. A number of wave convergences and divergences are generally witnessed along the coast. About 2 km south of the entrance channel there is a convergence between the wave rays B and C giving rise to wave heights as large as 2 m at the 2 fm line. Similarly the wave heights are large (2.4 m) just at the northern side of the entrance due to the sharp convergence of the wave rays F and G. The wave heights at all other points along the coast are around 1 m. The values of wave refraction function K [Table 1(i)] at 2 fm line for almost all the wave rays are less than unity except for the zones of convergence where K values exceed unity. The α varies between 8° and 16°, the maximum values being near the entrance. The orientation of the wave rays on the whole indicates a mean longshore component of energy directed towards south.

Distribution of wave-induced longshore currents computed on the basis of wave refraction for NE waves is shown in Fig. 2(B), while the computed current strengths are presented in Table 2(i). The contributions due to the oblique wave approach and the wave height variations alongshore are shown separately in columns 2 and 3 of the Table while the resultant currents are given in 4th column. Distribution of currents is discussed with reference to a number of points alongshore numbered (1), (2), (3), etc. The currents due to NE waves seem to be maintained mainly by the oblique approach since the currents in general are

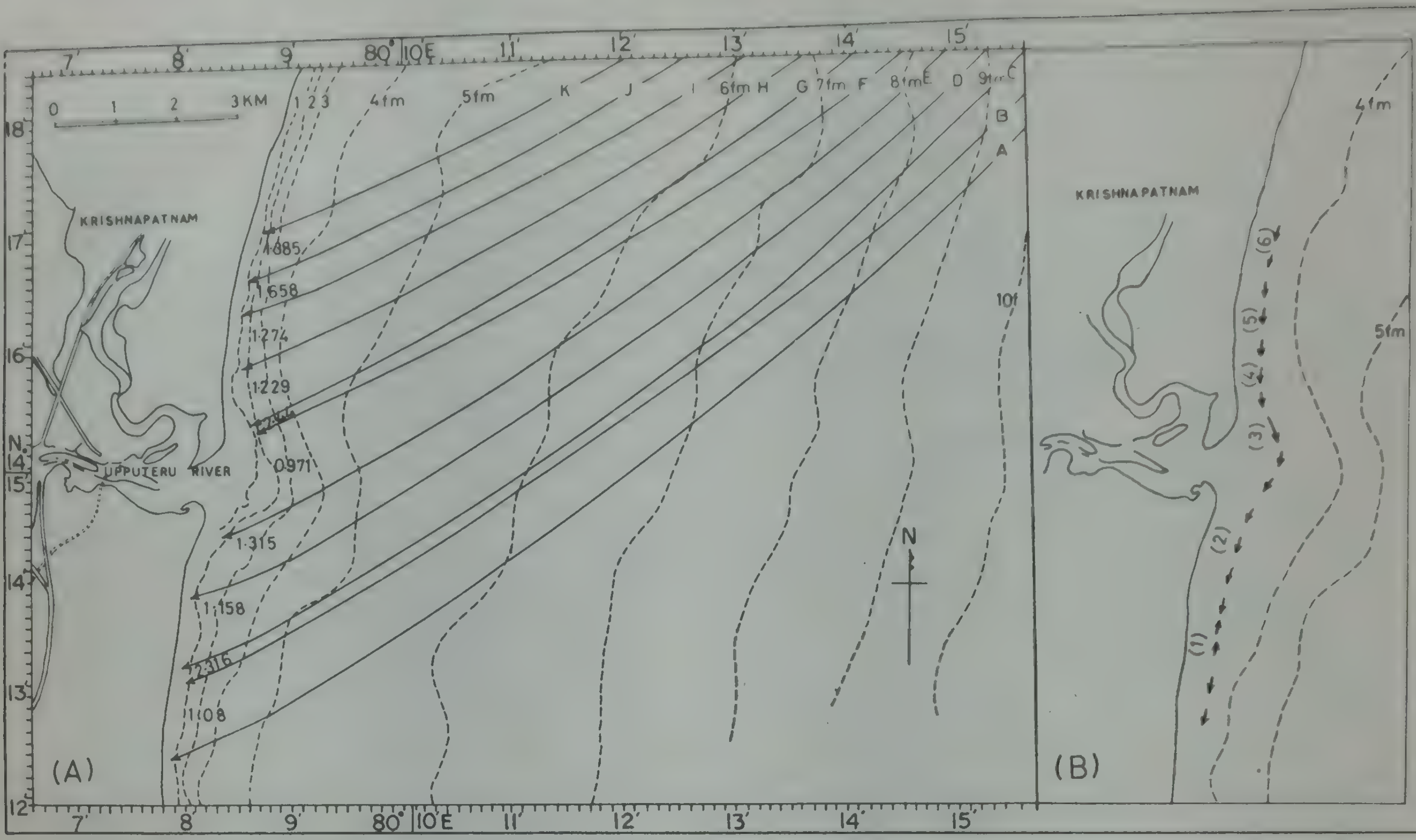


Fig. 2—(A) Wave refraction diagram for NE waves [Period 7 sec, deep water wave height = 1.6375m. Solid lines represent wave orthogonals and broken lines represent bottom contours. Numbers depict the wave heights in meters at the corresponding depth]. (B) Direction of longshore current for NE waves

directed towards south almost along the entire coast. However, between (1) and (2) a weak northerly current due to wave height variations seems to oppose the main southerly current where a small rip current may be generated. Just at the northern side of the entrance (point 3), there are strong currents of the order of 2 m/sec where the contributions due to wave height variations and angle of wave approach seem to add together. These currents can easily move the sediments across the mouth and keep the entrance open during the season of NE waves (November to January). The current strengths at all other points are around 0.8 m/sec. Due to the strong currents in this season, no silting of the mouth is likely to occur.

Fig. 3(A) shows the wave refraction pattern for the E waves. The general bending of wave rays indicate a northerly component of longshore wave energy. Distribution of wave rays along the coast is by no means uniform. Within a distance of about 2 km south of the entrance channel, 3 alternate zones of convergence and divergence are found. Wave heights at the zones of wave convergence are about 1.1 to 1.2 m while at the zones of divergence they are only about 0.6 to 0.7 m. There is a strong zone of convergence again just at the northern side of entrance where the wave heights are as large as 1.5 m. Distribution of wave energy towards north of the entrance channel is almost uniform with wave heights between 0.7 and 0.8 m except for a zone of convergence between wave rays P and Q when the wave heights are about 1.2 m. The wave refraction functions at 2 fm line for E waves are generally between 0.8 and 0.9 except near the entrance channel and the zones of convergence where *K* values are more than unity. The α seems to vary in general between 0.5° and 3° for E waves [Table 1(ii)].

The current distribution due to E waves are presented in Fig. 3(B), while the current strengths are given in Table 2(ii). South of the entrance channel the wave height variations alongshore seem to control the currents to a large extent. Between (1) and (3), a system of opposing currents related to the alternate zones of convergence and divergence is seen. The southerly current are however very weak (0.05 m/sec) while the northern current dominates (0.8 m/sec). Between (3) and (5), there is a system of opposing currents which may give rise to a rip current around the point (4). Just north of the entrance channel there are strong currents (1.1 m/sec) directed towards north. Further north of this point there are weak northerly currents (0.25 m/sec). The prevailing wave convergence at the entrance may not permit further silting of the entrance channel and the mouth will be open during the season of easterly waves.

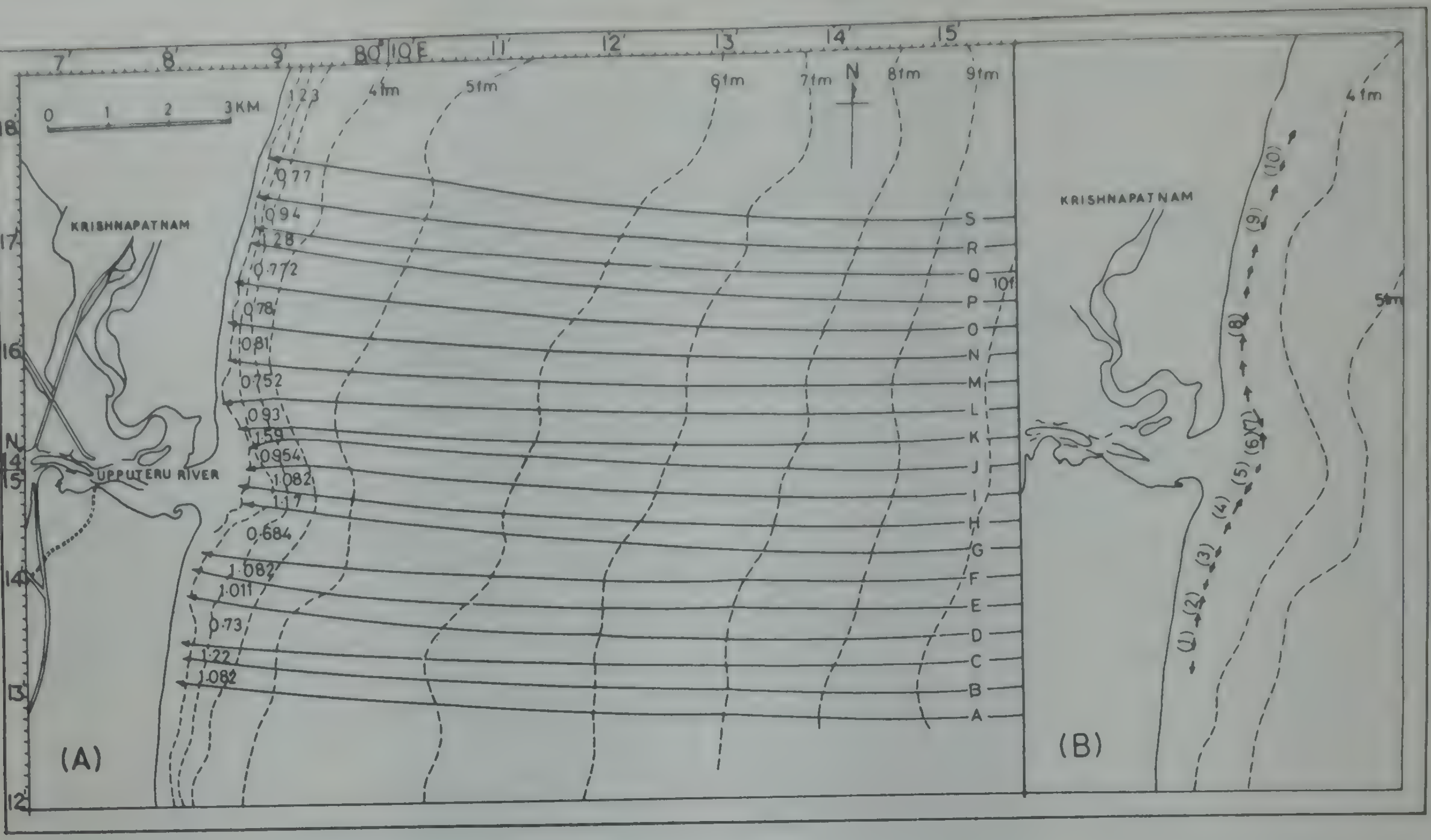
Fig. 4(A) shows the wave refraction pattern for the waves coming from SE. The disposition of the wave rays nearshore indicates a northerly component of

Table 1—Values of Wave Refraction Function, Direction Function and Wave Height at 2 fm Line for (i) NE Waves, (ii) E Waves and (iii) SE Waves

Wave ray	Refraction function *K*	Direction function α in deg.	Wave height m
		(i) NE waves	
A		8	
	0.617		1.08
B		12	
	1.323		2.316
C		14	
	0.661		1.158
D		14	
	0.751		1.315
E		15	
	0.555		0.971
F		15	
	1.394		2.44
G		13	
	0.702		1.229
H		10	
	0.728		1.274
I		10	
	0.947		1.658
J		14	
	0.791		1.385
K		16	
		(ii) E waves	
A		1	
	1.118		1.082
B		1	
	1.261		1.22
C		0.5	
	0.751		0.73
D		5	
	1.045		1.011
E		2	
	1.118		1.082
F		3	
	0.707		0.684
G		0.5	
	1.208		1.17
H		0.5	
	1.118		1.082
I		6	
	0.986		0.954
J		1	
	1.614		1.59
K		0.5	
	0.959		0.93
L		2	
	0.777		0.752
M		1	
	0.837		0.81
N		2	
	0.805		0.78
O		1	
	0.798		0.772
P		0.5	
	1.323		1.28
Q		0.5	
	0.959		0.94
R		2	
	0.791		0.77
S		1	
		(iii) SE waves	
A		12	
	0.986		0.892
B		5	
	0.986		0.892
C		5	
	1.08		0.977
D		5	
	1.046		0.947
E		11	
	1.118		1.011
F		9	
	1.015		0.917
G		9	
	1.015		0.917
H		11	
	1.08		0.978
I		7	
	0.872		0.789
J		7	
	1.261		1.141
K		6	
	0.791		0.715
L		6	
	1.118		1.011
M		2	
	1.08		0.978
N		4	
	1.323		1.196
O		7	
	0.845		0.772
P		8	
	1.096		0.991
Q		4	
	0.739		0.669
R		4	
	1.118		1.011
S		6	
	0.688		0.622
T		5	

alongshore wave energy. Distribution of wave energy is almost uniform along the entire stretch of the coast. However, a small zone of convergence is noticed again at the northern side of the entrance. It is interesting to note that the wave convergence at this point is more or less a permanent feature that occurs for waves from all the directions. The wave heights on the average are about 0.9 m during this season. About 3 km north of the entrance there are 2 zones of large divergence where the wave heights are relatively small. The *K* values and α values for different zones along 2 fm line are shown in Table 1 (iii).

For SE waves the longshore current [Fig. 4(B)] appears to be predominently towards north and is controlled largely by the direction of wave approach. The average current velocity [Table 2(iii)] is around 0.7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KRISHNAPATNAM
UPPUTERU RIVER
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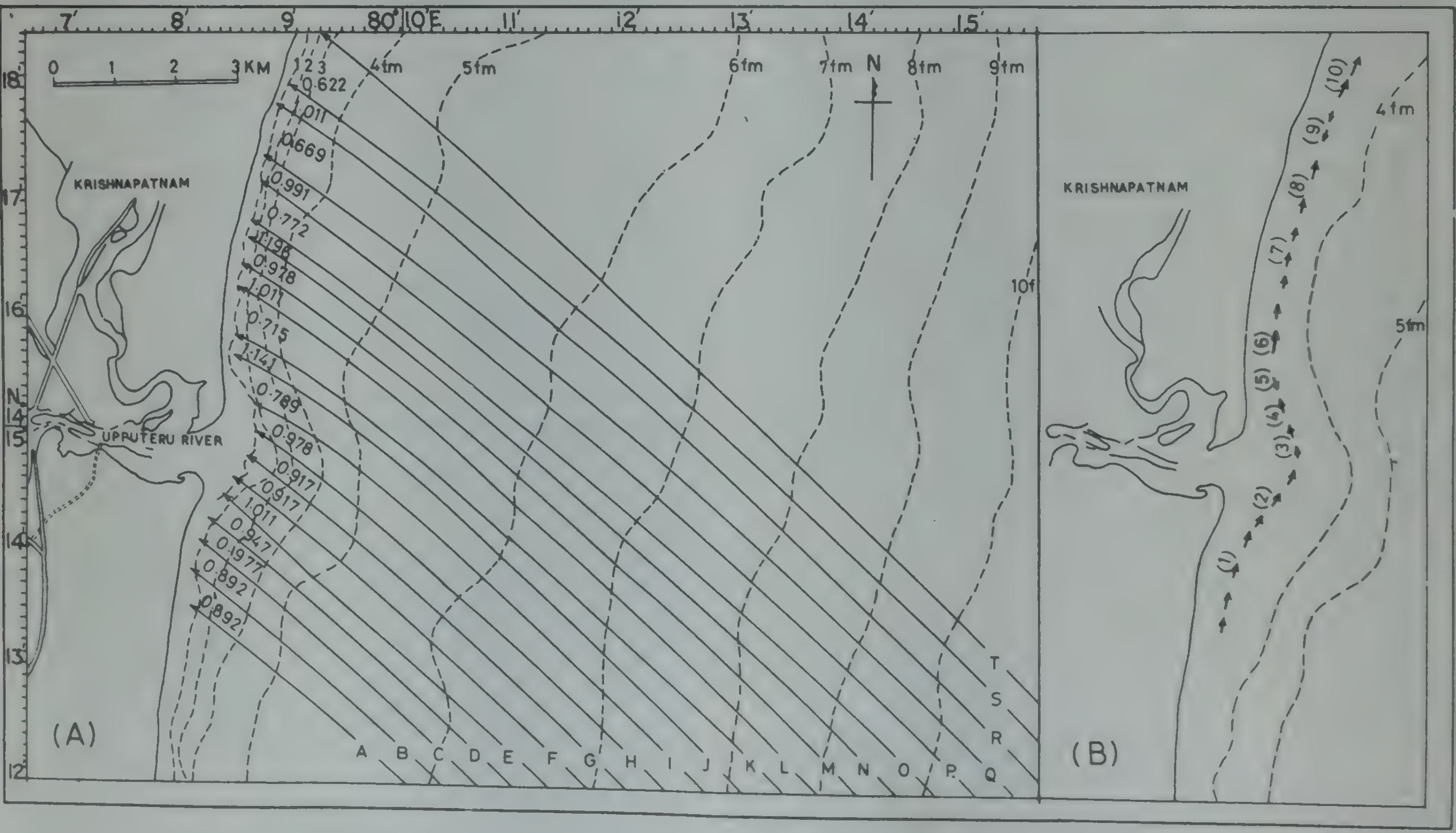
Fig. 3—(A) Wave refraction diagram for E waves [Period 7 sec, deepwater wave height = 0.868m. Other details same as in Fig. 2A]. (B) Direction of longshore current for E waves


7'
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KRISHNAPATNAM
UPPUTERU RIVER
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Fig. 4—(A) Wave refraction diagram for SE waves [Period 7 sec, deepwater wave height = 0.9124m. Other details same as in Fig. 2A]. (B) Direction of longshore current for SE waves

Table 2—Values of Wave-induced Currents due to (i) NE Waves (ii) E Waves and (iii) SE Waves for Different Points Alongshore

Point location	Currents due to oblique m/sec	Currents due to height variation m/sec	Resultant current m/sec	Direction towards
		(i) NE waves		
(1)	1.086	1.134	0.048	N
(2)	1.134	0.286	0.848	S
(3)	1.1	1.069	2.169	S
(4)	0.81	0.298	0.512	S
(5)	0.956	0.462	1.418	S
(6)	1.195	0.253	0.512	S
		(ii) E waves		
(1)	0.038	0.427	0.389	S
(2)	0.214	0.661	0.875	N
(3)	0.175	0.226	0.051	S
(4)	0.172	0.359	0.531	N
(5)	0.036	0.51	0.474	S
(6)	0.258	0.607	0.865	N
(7)	0.038	1.22	1.182	S
(8)	0.105	0.157	0.262	N
(9)	0.073	0.974	0.901	S
(10)	0.108	0.365	0.473	N
		(iii) SE waves		
(1)	0.525	0.075	0.45	N
(2)	0.643	0.133	0.776	N
(3)	0.64	0.144	0.496	N
(4)	0.486	0.359	0.845	N
(5)	0.46	0.462	0.002	S
(6)	0.42	0.591	1.011	N
(7)	0.287	0.269	0.018	N
(8)	0.41	0.225	0.635	N
(9)	0.238	0.262	0.024	S
(10)	0.369	0.392	0.761	N

m/sec directed towards north. At points (5) and (9) contributions due to the wave height variations seem to dominate resulting in southerly currents which oppose the north flowing main current. This may give rise to small rip current around (5) and (9). The currents are fairly strong near the entrance and could move the material across the mouth so that no further silting is likely to take place even during the season of SE waves.

Wave-induced currents along Krishnapatnam coast seem to be fairly strong during all seasons of the year. During northeast monsoon season, the currents are especially strong due to the combined effect of oblique wave approach and the wave height variation along the coast. The breakers on the average are of the order of 1 m, but just at the northern side of the entrance there seem to be heavy breakers due to the convergence of wave rays at this point. The northern side of the entrance is likely to be open during all seasons of the year and maintain larger depths as well. Further silting near the mouth is not likely to happen and the existing minimum depth may be maintained throughout the year. This is because of a general convergence of wave rays near the mouth. If the entrance of the mouth is deepend to facilitate navigation then the refraction patterns may change considerably resulting in the siltation at the entrance. If the tidal currents are sufficiently strong then there may not be much silting at the entrance and navigable depths might be maintained with some occasional dredging near the mouth. The present conclusions are based only on the studies of wave conditions and wave-induced currents off Krishnapatnam and should be considered as limited to that extent. Studies on the tidal currents, river currents and wind currents have to be undertaken simultaneously along with the wave studies for a better understanding of the problem.

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Wave Characteristics Off Paradip Port*

R VARADARAJULU
Department of Meteorology & Oceanography
and
M HARI KRISHNA
Department of Geography, Andhra University, Waltair 530 003

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Wave characteristics off the Paradip Coast have been studied from the IMD data. Predominant directions of the waves (frequencies > 10%) are SW, SSW, S, N and NE with frequencies in decreasing order. Large number of waves posses wave heights < 1.25 m and periods < 7 sec. On about 4% of days in an year waves with heights ranging from 3.75 to 4.75 m and periods > 17 sec prevail which coincides with the time severe stormy weather (wind speeds > 62.5 km/hr) occurs in the Bay of Bengal. Frequency distribution of waves from different directions during an year has been found to be closely related to the frequency distribution of surface wind directions off Paradip Coast.

Knowledge of high waves and their periods of occurrence in deep sea is important for navigation. Further, information on shallow water wave characteristics is essential for the design and development of harbours. Theories on the origin, growth and dissipation of waves have been established[1,2]. The deep sea waves, while propagating to distant coasts, undergo changes in their characteristics such as height and period in general and direction in particular[3,4]. The present investigation attempts to present wave characteristics in the deep sea in contrast to those in shallow water off Paradip. Further, distribution of wave characteristics during different seasons has been discussed in relation to distribution of winds over the sea surface during the corresponding seasons.

Materials and Methods

Wave heights, periods and directions between 18° and 22°N and 85° and 90°E published in the Indian Daily Weather Reports (for the years 1966 to 1975) have been analysed to study the average deep sea wave characteristics. Data on wave characteristics in shallow water off Paradip port (reported by the Port authorities during 1966 to 1975) have also been studied for obtaining the shallow water wave characteristics. The wind data reported along with the wave data have been analysed to obtain the mean wind characteristics over the sea surface. In addition wind characteristics at Puri (coastal station close to Paradip) have also been analysed and the average distributions presented.

Wave data have been analysed for wave characteristics dividing the wave heights (0-1.25, 1.251-2.25, 2.251-3.75 and 3.751-4.75 m) and wave periods (0-7, 8-11, 12-17 and 18-21 sec) for all the 16 directions. Similarly wind data off Paradip and Puri have also been studied for their frequency distributions from different directions and speeds. The mean distributions of wave characteristics have been presented in the form of seasonal and annual rose diagrams. Characteristics of shallow water waves are presented in the form of a table because the waves approach the coast only from a few directions.

Results and Discussion

Rose diagrams for wave height and period and wind speeds and coastal winds are given in Fig. 1. Mean yearly wave height and period and wind speeds are given in Fig. 2. Characteristics of shallow water waves are given in Table 1.

During winter (November-February) the waves (Fig. 1a and b) are predominantly from N, NE, ENE and E. While the propagation of waves from ENE and E is a consequence of cyclones prevailing in the southern Bay of Bengal, propagation from the rest of the directions may be the result of northeast monsoon winds, and the wave heights and periods usually range from 0 to 2.25 m and 0 to 11 sec respectively. During premonsoon (March-May) the direction of waves is predominantly between S and W with highest frequency from S. Wave heights and periods are usually < 2.25 m and < 11 sec respectively with occasional waves reaching the height of 3.75 m and period of 17 sec. During southwest monsoon (June-September) waves are frequent from SW while waves

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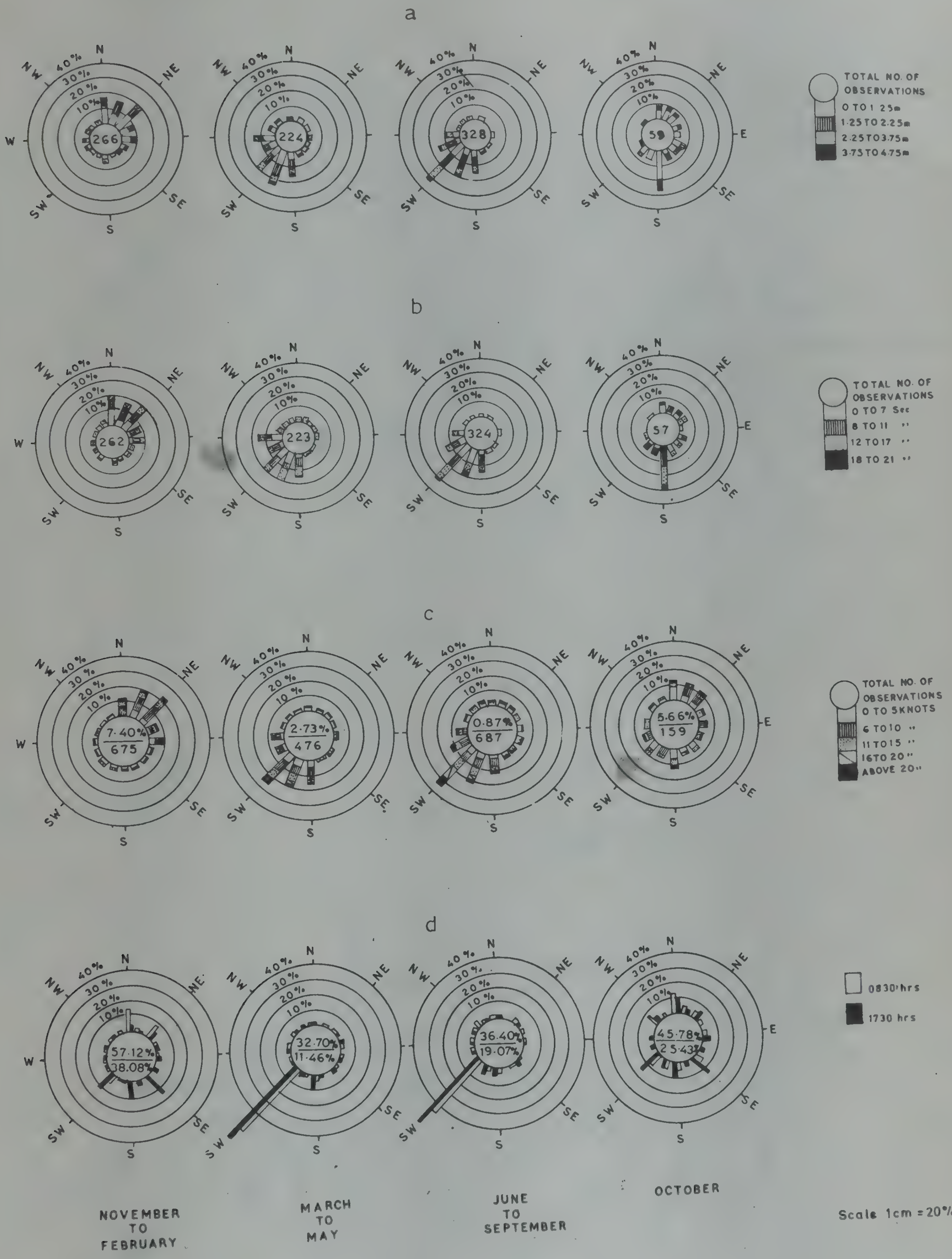

Fig 1—Rose diagrams for (a) wave height, (b) wave period, (c) wind speeds over the sea surface and (d) coastal winds [In (c) numerator indicates percentage number of days of calm periods and denominator the total number of observations. In (d) numerator indicates percentage number of days of calm periods and denominator the number of observations at 0830 hrs (open bar) and 1730 hrs (closed bar). Direction of wind is towards the centre of diagram]

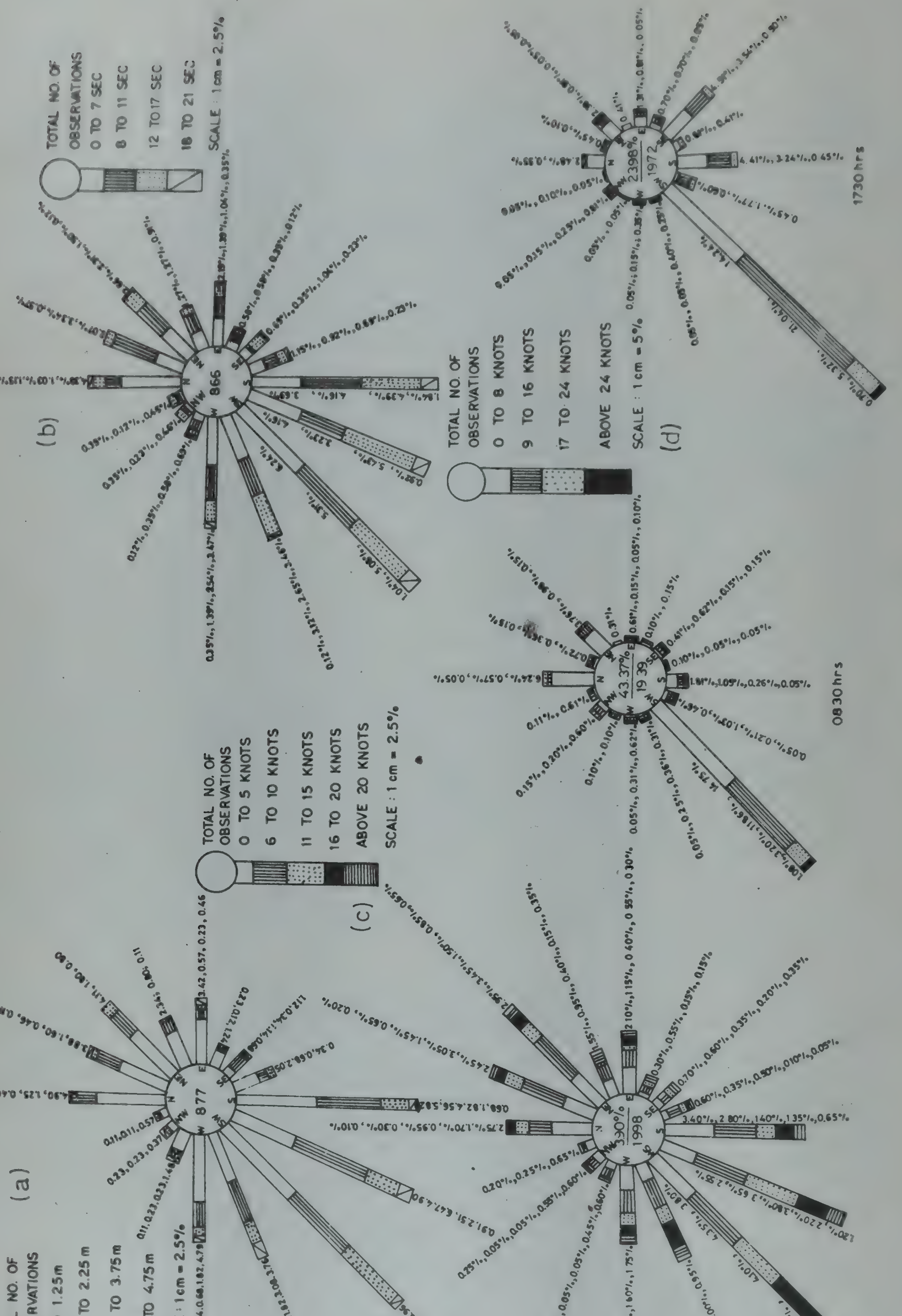

Fig. 2— Mean yearly rose diagrams for (a) wave height, (b) wave period, (c) wind speed and (d) wind speeds at 0830 and 1730 hrs [In (c) and (d) numerator indicates percentage of calm period of days and denominator the total number of observations]

Table 1—Percentage Frequencies of Shallow Water Wave Heights from Different Directions

Month	T	A	B	C	D	T	A	B	C	D
			E					ESE		
Jan.	1.8	1 4	0.4	—	—	7.7	6.8	0.8	0.1	—
Feb.	—	—	—	—	—	9.7	6.9	2.8	—	—
March	0.4	0.4	—	—	—	0.7	0.7	—	—	—
April	—	—	—	—	—	0.7	0.2	0.3	0.2	—
May	—	—	—	—	—	1.3	1.3	—	—	—
June	—	—	—	—	—	2.2	1.9	0.3	—	—
July	—	—	—	—	—	1.4	1.2	0.2	—	—
Aug.	—	—	—	—	—	2.9	1.0	1.5	0.4	—
Sept.	0.7	0.3	0.4	—	—	1.1	0.1	0.6	0.1	0.3
Oct.	0.9	0.5	0.4	—	—	5.1	1.5	2.0	1.3	0.3
Nov.	1.0	1.0	—	—	—	4.5	0.7	2.4	1.1	0.3
Dec.	0.9	0.9	—	—	—	10.4	8.9	1.6	—	—
			SE					SSE		
Jan.	38.1	33.3	3.3	1.5	—	4.6	4.1	0.5	—	—
Feb.	29.8	20.1	9.7	—	—	2.7	1.8	0.9	—	—
March	15.5	8.5	6.8	0.2	—	3.7	1.5	1.9	0.3	—
April	9.0	3.7	4.7	0.6	—	5.6	2.2	3.4	—	—
May	13.1	7.1	6.0	—	—	6.0	1.7	4.3	—	—
June	21.0	3.6	15.8	1.6	—	11.8	1.3	8.3	2.2	—
July	11.0	0.8	8.7	1.5	—	8.5	0.2	6.8	1.5	—
Aug.	14.1	3.0	8.1	3.0	—	7.0	0.6	5.6	0.8	—
Sept.	24.5	8.6	13.4	2.5	—	6.4	1.7	3.9	0.4	0.4
Oct.	25.0	20.6	3.9	0.5	—	7.3	5.1	1.9	0.3	—
Nov.	24.5	18.4	5.4	0.5	0.2	11.7	9.6	1.3	0.6	0.2
Dec.	33.9	29.5	4.4	—	—	7.2	5.3	1.9	—	—
			S					SSW		
Jan.	47.9	44.7	3.2	—	—	—	—	—	—	—
Feb.	57.7	46.9	10.6	0.2	—	—	—	—	—	—
March	67.0	42.5	23.3	1.2	—	3.7	2.7	1.0	—	—
April	73.8	35.4	34.5	3.9	—	4.2	1.5	2.7	—	—
May	71.7	35.6	35.1	1.0	—	2.9	0.7	1.6	0.6	—
June	63.1	29.6	27.4	6.1	—	1.2	0.2	1.0	—	—
July	66.7	27.0	31.5	8.1	0.1	7.1	0.4	4.6	1.8	0.3
Aug.	67.9	23.2	37.8	6.6	0.3	7.2	0.1	6.0	1.0	—
Sept.	57.4	37.2	16.8	3.0	0.4	9.2	2.6	4.5	1.7	0.4
Oct.	60.8	49.0	11.2	0.6	—	0.9	0.6	0.3	—	—
Nov.	57.1	51.4	4.5	0.6	0.6	0.8	0.8	—	—	—
Dec.	47.6	46.5	1.1	—	—	—	—	—	—	—
			SW					WSW		
Jan.	—	—	—	—	—	—	—	—	—	—
Feb.	—	—	—	—	—	—	—	—	—	—
March	8.6	6.1	2.5	—	—	0.3	0.3	—	—	—
April	6.8	2.3	4.3	0.2	—	—	—	—	—	—
May	4.8	3.0	1.7	0.1	—	0.1	0.1	—	—	—
June	0.7	0.3	0.4	—	—	—	—	—	—	—
July	5.3	0.3	2.6	2.3	0.1	—	—	—	—	—
Aug.	1.0	0.2	0.1	0.7	—	—	—	—	—	—
Sept.	0.7	0.7	—	—	—	—	—	—	—	—
Oct.	—	—	—	—	—	—	—	—	—	—
Nov.	0.5	0.5	—	—	—	—	—	—	—	—
Dec.	—	—	—	—	—	—	—	—	—	—

Wave heights (m): A, <1.25; B, 1.251 to 2.25; C, 2.251 to 3.75; D, 3.751 to 4.75

T = Total percentage in the corresponding directions from SSW, W and WSW are also significant. Wave heights usually range from 1.25 to 3.75 m with occasional occurrence of high waves with heights >3.75 m. Wave periods range from 8 to 17 sec and occasionally exceed 17 sec. During October the most frequent direction of wave propagation is S with heights usually <1.25 m and wave periods up to 17 sec.

Mean annual diagram (Fig. 2a and b) clearly indicates that large number of waves propagate from SW, S and SSW with heights and periods ordinarily <2.25 m and <11 sec respectively. The wave heights range from 3.75 to 4.75 m on about 4.11% of the days which is in good agreement with the number of days of severe cyclonic weather (wind speeds >62.5 km/hr) over the Bay of Bengal. The shallow water waves (Table 1) propagate between E and SW through S with predominance from SE and S and these waves have heights usually <1.25 m and rarely exceed 3.75 m. Frequency of occurrence of waves with heights >2.25 m has been considerably reduced and this clearly indicates that waves have been damped by travelling from deep sea into the shallow water. Similarly, the frequency of occurrence of waves limited to a fewer directions in shallow water may be attributed to the refraction of waves[3,4] (waves continuously refract while travelling in shallow water when the depths are less than half the wave length) towards coast normal while propagating in the shallow water.

Distribution of winds (Figs. 1c and 2c) shows that strong winds blow from SW and SSW from March to September and during November to February winds blow frequently from NE and NNE. The coastal wind direction (Figs. 1d and 2d) is predominantly SW during the year and further, on a large number of days calm winds prevail. Differences in the wind distribution over the sea surface in the deep sea and at a coastal station appear to be related to the land and sea breeze near the coast. However, the influence of coastal winds on the swell originating in the deep sea and propagating towards the coast may be disregarded.

Deviations in the distribution of wave frequencies with those of winds do exist due to the changes in the characteristics of the waves while propagating to long distances from the generating area. However, the frequency distribution of waves from different directions appears to be closely related to the distribution of winds over the Bay of Bengal. The wave characteristics in the deep sea off Paradip port are similar to the distribution of wave characteristics off Visakhapatnam[5] and Madras[6] coasts and these may be due to the similarity of the monsoon winds off the east coast of India.

Acknowledgement

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Seasonal Variations in Hydrographic Conditions of Estuarine & Oceanic Waters Adjoining the Old Mangalore Port

M P M REDDY, V HARIHARAN & N P KURIAN
University of Agricultural Sciences, College of Fisheries, Mangalore 575 002

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To understand various processes responsible for siltation in the entrance channel and in the sand bar area, near the old Mangalore port, seasonal variations in temperature, salinity, suspended sediment load, currents and extinction coefficient in the Netravathi-Gurpur estuary and in the sea near the sand bar were studied in relation to tides. Hydrographic characteristics in the estuary showed marked seasonal changes and were influenced by tides to a considerable extent. In the sea, seasonal variations of these parameters were less marked and the effect of tides was not significant. Salinity and temperature at both places were maximum during premonsoon in general. Suspended sediment load was always high in the estuary than in the sea and was maximum in the monsoon season. Currents in the estuary were controlled by tides as well as by the river flow particularly in the monsoon season; whereas currents in the sea mostly followed the general circulation pattern. Extinction coefficient values were higher in the monsoon at both places due to increase in the particulate matter from inland drainage.

The old port of Mangalore is situated on the Karnataka coast of the Arabian Sea (Fig. 1). Two rivers, Netravathi and Gurpur meet in the port area and flow together for a short distance before reaching the sea. Harbour facilities for general cargo are located in the left coast of the river Gurpur. The right coast of the Netravathi river serves as a fishing harbour. Thus, the port is important both for general cargo and fishing vessels.

The entrance to the port is through the mouth of the Netravathi-Gurpur estuary. There is a sand bar in the sea just outside the entrance, the depth over which varies from season to season and from year to year. The navigation channel near the mouth of the estuary is closed for vessels during monsoon because of the increased siltation in the channel entrance and in the sand bar area. In order to understand the processes of siltation in the harbour entrance area and to obtain information for planning the port development programmes and subsequent maintenance works, the College of Fisheries has undertaken detailed investigations on the hydrography including circulation and sediment load of the waters adjacent to this port. Since the harbour entrance area is dominated by periodic tidal exchanges of estuarine and oceanic waters, as a first step, comparative seasonal study of the hydrographical features including suspended sediment load of the sea waters adjoining the sand bar with those of the estuarine waters at the mouth over a tidal cycle period has been undertaken.

Materials and Methods

Two stations, one located in the Netravathi-Gurpur estuary near its mouth (st A) representing the estuarine conditions and the other on the sea side of the sand bar (st B) representing the oceanic conditions, were selected for observations (Fig. 1). From the estuarine mouth, st A was about 100 m inside the estuary and st B about 3.65 km in the sea. Average depths at sts A and B were 6 and 12 m respectively. Observations were made in September and December 1976 and April 1977 to study

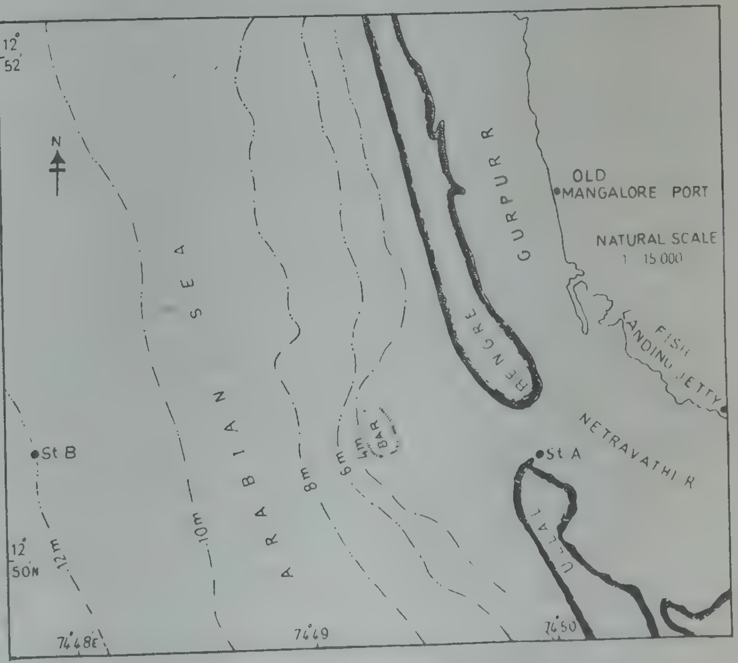

Fig. 1—Location of stations

the seasonal hydrographic conditions prevailing in monsoon, postmonsoon and premonsoon seasons. Data at the 2 stations were collected almost simultaneously (with a time difference of about 30 min) at an interval of about 2 hr for a tidal cycle period by moving the mechanised boat *MF V Silver Belly* from one station to another. Surface and near bottom water temperatures were recorded using standard thermometers. Water samples were collected from surface by a plastic bucket and from near bottom by a Nansen reversing water bottle. Salinity of the water samples was determined by the titration method and suspended sediment load was estimated using the standard filtration technique. Surface and bottom currents were measured using Lynx and Kelvin Hughes current meters. Transparency of waters was measured by means of a Secchi disc and extinction coefficient value (K) calculated using the formula $K=\frac{1.7}{D}$, where D is the Secchi disc reading in metres[1]. Predicted tide data[2] for Mangalore waters were used while comparing the variation of the hydrographic parameters with tides.

Results and Discussion

Monsoon season—Fig. 2 shows variations of different hydrographic parameters during this period. Temperature at st A varied between 26.5° and 29.6°C and at st B between 26.3° and 27.9°C. Surface water temperature was higher than the bottom water temperature at both stations. The generally low temperatures at st B were consistent with the conditions of sea water at this time. High temperatures of the estuarine waters were due to solar heating of the landlocked estuary. Greater variation of temperature was observed for the estuarine waters than the oceanic waters. This could be due to the characteristic feature of the estuary where brackish or freshwater influence was dominant. Temperature variations of the estuarine waters clearly indicated the influence of tide. Such tide controlled changes in temperature during the monsoon season were observed also in Mandovi[3] and in Zuari[4] estuaries.

Salinity variations in the estuary were considerably higher during this season. Salinity of waters varied from 14.6 to 26.3‰ at st A. In comparison, salinity variations at st B were less (29.6 to 30.6‰). Higher range of salinity and relatively steep vertical gradient encountered in the estuarine mouth region showed the stratification caused by considerable run off during this period. Decrease in the vertical salinity gradient during the flood tide and increase in the gradient during the ebb tide, observed in the estuary, appeared to be associated with the upward and downward movement of the salt wedge. Suspended sediment load was maximum in the estuarine waters during this season. A semi-tidal fluctuation of the suspended load was observed at st A, and also the waters contained more suspended sediment during the falling tide with a maximum value of 178 mg/litre. In the oceanic waters (st B), maximum value of suspended load was 84 mg/litre which is about half the maximum value of the estuarine waters. This is in agreement with the finding that most intense period of suspended sediment transport in estuaries occured during the periods of high river discharge[5-7]. In general, suspended load was noticed to increase with depth.

In the estuarine waters (st A), maximum speeds of surface and bottom currents were about 98 and 104 cm/sec respectively during flood tide, while during ebb tide, maximum speeds of about 130 and 108 cm/sec were encountered in the surface and bottom layers respectively. Ebb currents were stronger than the flood currents mainly due to the run off. At st B, maximum current speed was 29 cm/sec at the surface and 25 cm/sec near the bottom. Currents here were generally directed towards south. Another feature at this station was that the currents were not much influenced by tide.

Extinction coefficient values at both stations were high in this season (Table 1). Relatively higher extinction coefficient values were noticed in the estuary than in the sea. This is due to the increase in the amount of suspended load as a result of the inland drainage brought by the rivers during the rainy season.

Postmonsoon season—Water temperature varied from 26° to 29°C at st A and from 26.9° to 29.8°C at st B (Fig. 2). Surface waters were generally warmer than bottom waters except in morning hours. Higher temperature of surface water as the day progressed was due to higher effect of solar heating at the surface layers. In the sea also, bottom water temperatures were higher than the surface water temperatures in morning hours. Another feature was that the temperature in the sea was generally higher than the temperature in the estuary. This may be due to the fact that winters are cooler in the estuary than in the sea. Salinity values varied from 24.39 to 29‰ in the estuary and from 31.98 to 33.74‰ in the sea. In general, there was a depthwise increase in salinity in both the regions. Marked tidal influence on salinity variations was evident in the estuary. Salinity values increased with the rising tide and decreased with the falling tide. Such clear influence was not found in the sea.

At st A, suspended sediment load varied between 28 and 38 mg/litre at surface and between 38 and 52 mg/litre near bottom. Relatively high values were found during ebb tide. At st B, suspended sediment values varied from 8 to 14 mg/litre at surface and from 12 to 19 mg/litre near bottom. During ebb tide, maximum current speeds of about 70 cm/sec at surface and 52 cm/sec near bottom were attained in the

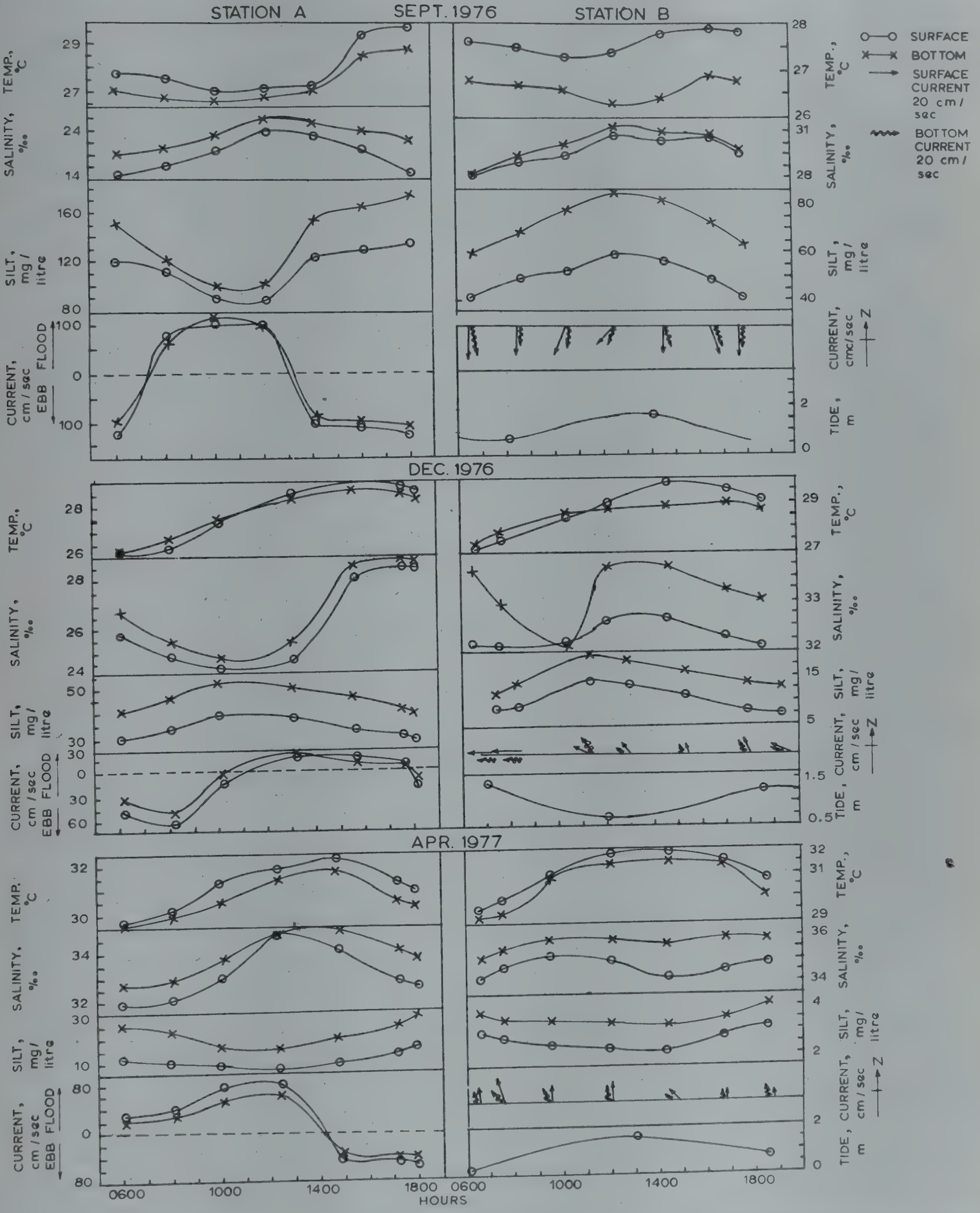

Fig. 2 — Variation of temperature, salinity, suspended sediment load (silt in suspension) and current with tide in the estuary (st A) and in the sea (st B) during monsoon (September 1976), postmonsoon (December 1976) and premonsoon (April 1977)

Table 1—Extinction Coefficient (K) Values at Sts A and B

September 27, 1976				December 28, 1976				April 20, 1977			
St A		St B		St A		St B		St A		St B	
Time	K	Time	K	Time	K	Time	K	Time	K	Time	K
0800	2.54	0830	1.82	0800	1.65	0730	1.05	0800	1.24	0730	0.9
1000	2.46	1030	1.6	1000	1.55	1020	0.98	0950	1.19	0930	0.83
1200	2.36	1230	1.57	1300	1.45	1200	0.9	1220	1.15	1200	0.8
1400	2.38	1430	1.62	1530	1.48	1430	0.92	1445	1.18	1425	0.82
1600	2.42	1630	1.65	1730	1.6	1700	0.99	1715	1.25	1645	0.88

estuary. Surface currents were higher than the bottom currents except during the middle of the flood tide period. In the sea, maximum speeds of 37 cm/sec at surface and 28 cm/sec near bottom were noticed and currents were directed generally between west and northwest during this period. Values of the extinction coefficient were somewhat less at this time due to the decrease in the amount of sediment brought by the rivers.

Premonsoon season—During this period, water temperature varied from 29.6° to 32.4°C at st A and from 29.3° to 32°C at st B (Fig. 2). In general, there was a depthwise decrease of temperature at both the stations. It was also noticed that the waters in the estuary were somewhat warmer. Thermal variations in the estuary appear to have been influenced both by tide and insolation during this season. In the estuary, salinity varied from 32 to $34.83^{\circ}/_{oo}$ during the entire tidal cycle period. Maximum salinity was attained both at surface and bottom at the maximum flood time. Salinity values varied between 34.2 and $35.9^{\circ}/_{oo}$ in the sea. The influence of tide on the salinity variation at st B was not noticed during this time also.

In the estuary, suspended sediment load varied between 8 and 29 mg/litre. In general, there was an increase in suspended sediment with depth. Another characteristic feature was that the values of suspended load were slightly higher at the time of ebb than at the time of flood. Suspended sediment values in the sea during this period were <5 mg/litre. Maximum current values of 80 cm/sec at surface and 60 cm/sec near bottom were observed during flood tide in the estuary while the maximum ebb current values were 50 cm/sec at surface and 40 cm/sec near bottom respectively. Thus, during this period flood current was faster than the ebb current. This could be related to the dominance of the tide resulting from negligible run off. In the sea, current speeds were <20 cm/sec. Generally the currents were directed towards north at st B. Extinction coefficient values were relatively lower at sts A and B during this period when compared with monsoon and premonsoon seasons (Table 1). This may be attributed mainly to the low sediment content of the waters due to the negligible run off.

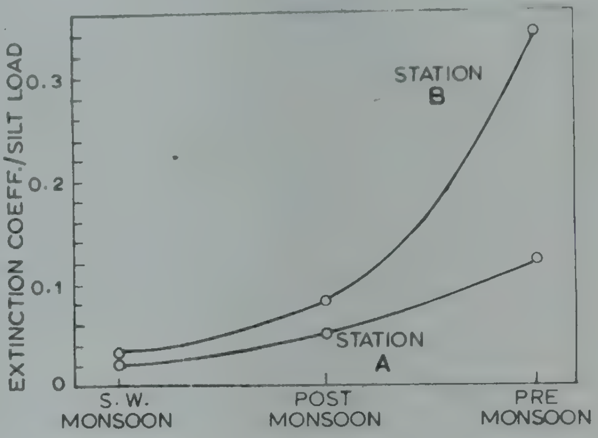

Fig. 3—Variation of extinction coefficient per unit silt load of surface waters in the estuary and in the sea during different seasons

Fig. 3 gives the seasonal variation of the extinction coefficient per unit silt load of surface waters. It is interesting to note that the extinction coefficient values per unit silt load during different seasons were not constant as it should have been if the silt load was to be the only factor determining the extinction coefficient value. The values showed progressive increase from a low value during the SW monsoon period to a high value during the premonsoon, the corresponding values being more in case of sea waters than in estuarine waters. This increase in the values of extinction coefficient per unit silt load during the post and premonsoon seasons could be attributed to difference in the optical quality of the waters eventhough the suspended sediment values decreased in these seasons. The increased values may be due to the increase in light absorption of the suspended sediment and to the decrease in the planktonic biomass. Studies on the plankton production along the west coast of India have revealed that planktonic biomass was maximum during the SW monsoon and decreased thereafter[8,9].

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Hydrographic Characteristics & Tidal Prism at the Cochin Harbour Mouth*

V S RAMA RAJU, P UDAYA VARMA & ABRAHAM PYLEE
National Institute of Oceanography, Regional Centre, Cochin 682018

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Diurnal and seasonal variations (May 1975 to April 1976) in hydrographic characteristics at the inlet of the Cochin Harbour are presented. During the SW monsoon season under the predominant influence of fresh water influx into the estuary no appreciable variations in the temperature and salinity values of the thin surface layer (< 4 m) are observed in relation to tide; whereas the subsurface water (4 m to bottom) shows close relation with the tide. Significant vertical gradients in temperature and salinity are noticeable between surface and bottom layers during this season. Prominent saline wedge is formed with the flood current in this season and during the ebb current homogeneous water of low salinity (< 10‰) pervades the entire depth of the harbour mouth. Mean vertical salinity profiles for the monsoon, post and premonsoon seasons indicate that the highly stratified conditions that exist during the monsoon season gradually change to partially mixed and homogeneous conditions of the post and premonsoon periods apparently due to decreasing river flows and increasing tidal influence. Maximum velocity of the current observed is 174 cm/sec which occurs during the ebb current of the spring tide of the postmonsoon season. Tidal prism in the premonsoon season during which time the fresh water addition to backwaters is least is found to be $31.5 \times 10^6 m^3$. During the other seasons, the values of tidal prism vary between $9.5 \times 10^6 m^3$ and $132 \times 10^6 m^3$. Factors effecting the stability of the inlet are discussed.

The Cochin backwaters estuarine system is formed by an offshore bar built along the shore extending from Cranganore in north to Alleppey in the south covering a length of about 90 km. The estuary is wide (16 km) in the Vembanad Lake area and several narrow canals drain water into the backwaters. Major perennial rivers—the Periyar, the Muvattupuzha and the Pamba—discharge fresh water directly into this estuarine system. The Cochin Harbour mouth is the major inlet connecting the backwaters to the Arabian Sea and the 2nd inlet at Azhikode is relatively shallow. A 3rd opening exists near Thuravur, but it remains closed most part of the year except during floods in the monsoon season. This 3rd opening has no or negligible influence on the backwaters.

Although hydrographic characteristics of the backwaters have been described[1-11], no detailed information is available on the intensity of the currents at the surface and subsurface levels and the associated exchange and mixing of the estuarine water with the Arabian Sea coastal waters. It is, therefore, important to study in detail hydrographic characteristics including volume transport across the harbour mouth to know the problem of sedimentation in the harbour, the stability of the inlet, and discharge of pollutants introduced into the backwaters, for model studies and for various harbour development works.

In this paper, hydrographic conditions at the harbour inlet along with volume transports are presented. Factors effecting the stability of the inlet are also briefly discussed.

Materials and Methods

As part of the studies on hydrographic conditions in the inner harbour of Cochin Port for harbour development works undertaken by NIO, extensive data have been collected during May 1975 to April 1976 on temperature, salinity, suspended sediment load and current from 30 stations in the inner harbour region.

The semi diurnal tide at Cochin has a maximum range of 1 m. The diurnal mean sea level is normally low during the monsoon season compared to post and premonsoon periods.

A 30 ft motor boat was moored to anchored buoys for observations. Three stations, A, B and C (Fig. 1) were covered along the cross section at the inlet between Fort Cochin and Vypeen Island. Observations were made at or around Full and New Moon days to represent spring tide conditions and about a week after that to represent neap tide conditions. A total of 6 days observations were made in different months. On each day, continuous hourly observations from surface (0.5 m below) to bottom (1 m above) were made at intervals of 2 m depth. Currents were measured at all the 3 stations and the temperature, salinity and suspended sediment load observations were made at mid station B. Bottom soundings were also taken using a lead line. These observations covered a total of 3 spring and 3 neap tide conditions. Some practical difficulties were encountered at the inlet section partly due to drifting of the anchors or snapping of the anchor ropes under the effect of strong currents at mid tide timings.

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*Paper presented at the symposium on Environmental modelling of physical oceanographic features as applied to Indian Ocean, NPOL, Cochin, February 1978

Surface samples were collected by a plastic sampler, and subsurface samples by a specially designed glass stoppered bottle or an indigenously fabricated plastic sampler. Salinity and temperature of most of the samples were determined using a T-S bridge and the values were read up to first decimal. A few samples were analysed for salinity by normal titration method.

Suspended sediment load was determined by filtration technique using Whatman filter paper No. 42. The currents were measured using a direct reading Plessey current meter which gave integrated values of the current over a period of 28 sec and the direction with reference to magnetic north.

Results and Discussion

Bottom profile of inlet—Cross sectional bottom profile of the inlet between Fort Cochin and Vypeen is shown in Fig. 1. The maximum depth of the inlet is 17 m below the chart datum occurring within a distance of 40 m from the Fort Cochin bank. The inlet bottom slopes steeply with a gradient of 1:2 on the Fort Cochin side and less steeply with a gradient of 1:6 on the Vypeen side. The central part of the inlet bottom gradually slopes to its maximum depth with a gradient of 1:36. This bottom profile represents the condition of dynamic equilibrium as a result of adjustment in topography under the influence of natural factors and no dredging is done to maintain the required depths for safe navigational purpose.

Temperature—Diurnal variation of temperature for the spring tide on 24-25 July 1975 (monsoon season) is shown in Fig. 2A. Variation of temperature is from 24° to 29°C, the surface water usually recording higher value. While the difference in surface water temperature with the tide is only 1.5°C, the subsurface water from 4 m to bottom shows a difference of 4°C with the tide. Vertical temperature gradients vary from 0.36° to 0.1°C/m between flood and ebb tides respectively. The increasing subsurface temperatures are associated with the progress of ebb flow and the decreasing temperatures are associated with the progress of flood flow. Similar variation of temperature with tide is noticed during the neap tide also. Low subsurface temperatures are attributed to the incursion of cool upwelled water from the shelf region into the backwaters[4]. The lowest annual temperature of the Cochin backwaters usually occurs during the monsoon season coinciding with the low temperature period of the coastal waters[10,12]. The temperature 24° to 25°C of the bottom water at the inlet during flood tide seems to be due to the inflow of mixed subsurface nearshore water of 20 m depth (temp. 20°-23°C) with that of the estuarine water.

Spring and neap tide observations in December 1975 and April 1976 falling in the post and premonsoon seasons respectively do not show any clear relationship between the surface or subsurface temperature with the tide. Also vertical temperature gradients are small (0.07°C/m) and the temperature varies between 28° and 31°C.

Salinity—Typical diurnal variation of salinity during the same period as for temperature is given in Fig. 2B. The thin surface layer (<4 m) shows salinity variation from almost freshwater to $9^{o}/_{oo}$, but the variation has no relationship with the tide. This indicates the predominant role of the freshwater flow over the tidal flow in the surface layer at the inlet which

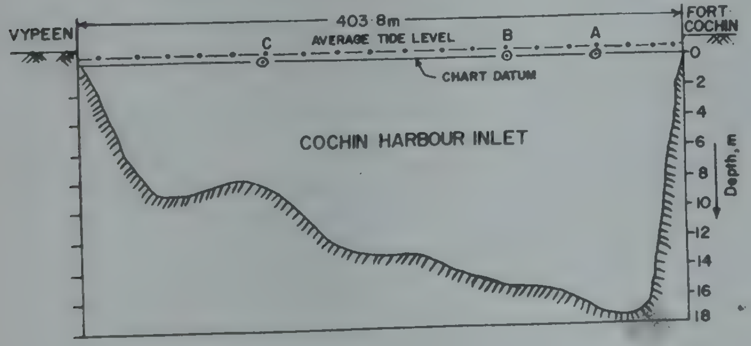


Fig. 1—Cross sectional bottom profile of Cochin Harbour inlet [Lat. 9°58′N, long. 76°14′30″E. Cross sectional area (m²) with reference to average tide level (April 1976): 0-4 m, 1567; 4-8, 1469; 8-12, 1106; 12-16, 675; and >16, 80]

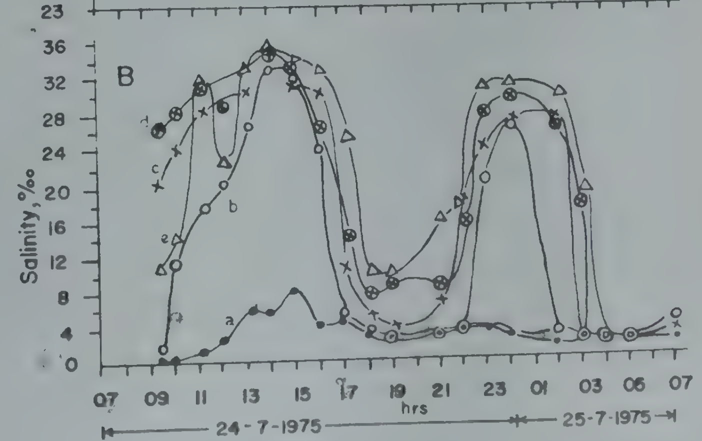


Fig. 2—Diurnal variation of temperature (A) and salinity (B) at station B [Depth (m): a, 0; b, 4; c, 8; d, 12; and e, bottom]

may prevail up to some distance from the coast along the approach channel. The subsurface layer shows wide variation from 2 to 34‰ and the variation shows close relation with the tidal flow, the higher salinity values occurring at HHW or HW and the lower values at LLW or LW timings. Except during the slack periods, marked variations occur in subsurface salinity with the tide leading to steep salinity gradients in the vertical and fast changing salinity conditions, which are typical of this estuary during monsoon season. Similar conditions are observed with the neap tide in July 1975.

Diurnal variations of salinity at the spring tide of December 1975 indicates somewhat similar conditions as those of monsoon, but with reduced salinity variations (12 to 32‰) between surface and bottom layers. Also, during this season, surface and subsurface salinity shows close relation with the tidal flow unlike during monsoon period indicating reduced role of the freshwater discharges over the tidal flow in the surface layer (<4 m).

Premonsoon spring and neap tide diurnal variations of salinity, observed during 12 to 13 April 1976 and 21 to 22 April 1976 respectively, show salinity variation of 30.5 and 35‰, which has no relationship with the tidal flow.

Mean vertical salinity profiles drawn for all the days of observations are presented in Fig. 3. Steep salinity gradient (of the order of 1.6‰/m), even in the mean values during monsoon season, coupled with low temperatures of bottom layers signify highly stratified conditions. High salinity, low temperature (therefore high density) bottom water moves through the inlet as a saline wedge prominently during flood tides and spreads into the inner channels of the harbour at the bottom.

During postmonsoon season the vertical salinity gradient (0.6‰/m) is smaller indicating partially mixed conditions. In premonsoon season, the mean vertical salinity gradient is least indicating well mixed conditions. Thus from the mean vertical salinity distribution, it can be inferred that the hydrographic conditions at the inlet change gradually from highly stratified to partially mixed and well mixed state as the seasons advance from monsoon to post and premonsoon periods respectively. A salinity change of <50% between surface and bottom water is taken as an indication for well mixed condition and 50 to 75% for partially mixed and >75% for stratified condition.

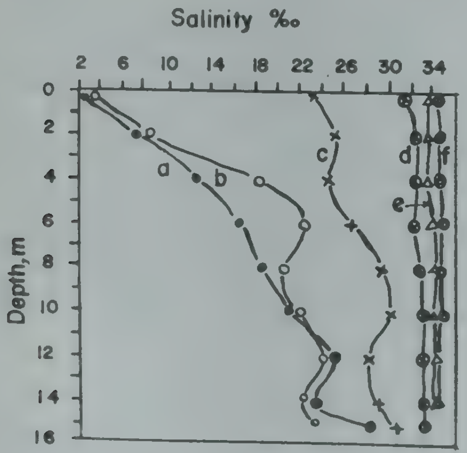


Fig. 3—Mean vertical salinity profile at station B during SW monsoon, pre and post SW monsoon seasons [a, spring—24 to 25 July 1975; b, neap—31 July to 1 August 1975; c, spring—2 to 3 December 1975; d, neap—5 to 6 February 1976; e, spring—12 to 13 April 1976; f, neap—21 to 22 April 1976]

Saline wedge—Vertical salinity variation at hourly intervals (Fig. 4) shows that a thin surface layer of low salinity (<10‰) up to a depth of 2 m overrides the high salinity (25-30‰) bottom water (6 to 16 m) during the flood flow and a marked saline wedge is formed at the inlet. But the saline wedge disappears during the low tide when the entire inlet is occupied by low salinity (<10‰) water under the combined influence of the ebb current and the outflow of the freshwater through the inlet. One or 2 hr after the flood tide begins, intrusion of the high salinity water can be noticed first near the bottom and later pushing up the low saline water or freshwater to the surface. Similar features of saline wedge are noticed during the neap tide observations in July 1975. The intrusion of saline wedge and its characteristics are important for model studies, improvement in navigation, flood control and disposal of waste material through the inlet.

During the postmonsoon season (December 1975) saline wedge is noticeable for a short duration during the flood flow at certain favourable conditions when fresh water discharges are high, but the salinity difference (10‰) between surface and bottom layer is much smaller compared to that of the monsoon season. During the premonsoon season (April 1975), homogeneous water of salinity around 35‰ is noticed at the inlet from surface to bottom and it is independent of the tidal flow.

Suspended sediment load—Hourly values of suspended sediment load, observed at the inlet, show very high fluctuations at short intervals both in space and time as they did at other stations in the inner harbour. Diurnal variations of suspended sediment load are studied in relation to tide and current but no definite relationship is noticed. Gopinathan and Qasim[8] have reported that suspended material in the estuary varies markedly with the state of the tide which is not noticed in the present observations. Therefore, an attempt has been made to average the hourly values and study them separately for spring and neap and flood and ebb flow during the 3 seasons to know the general trend (Fig. 5). A general increase in the sediment load from the monsoon season to post and premonsoon seasons can be seen, the highest values occurring during the postmonsoon season. Also suspended sediment load is higher with increasing depth. Higher sediment load during post and premonsoon seasons than in monsoon season may be partly due to the dredging operations being carried out in the outer channel of the harbour at that time.

Vertical variation of annual mean suspended sediment load for ebb and flood is shown in Fig. 6. The annual mean values vary between 25 and 50 mg/litre. The mean sediment load during flood tide is higher than at ebb tide indicating that during an average tidal period of equal flood and ebb, more suspended sediment moves into the harbour with the flood current.

Current—Diurnal variation of current at spring tide on 24-25 July 1975 at the inlet is shown in Fig. 7. In the monsoon season, ebb currents predominate in intensity and duration at all depths. At times, during the rising tide, the surface flow shows high ebb velocities while the tide rises solely due to the flood current in the subsurface layers. Similar dominant ebb currents are observed during the neap tide of the monsoon season. In the other 2 seasons, mostly rythemic variations of flood and ebb currents take place throughout the depths with rising and falling tides.

Highest velocity observed in the inlet is 174 cm/sec. It occurs during the ebb current of spring tide in the

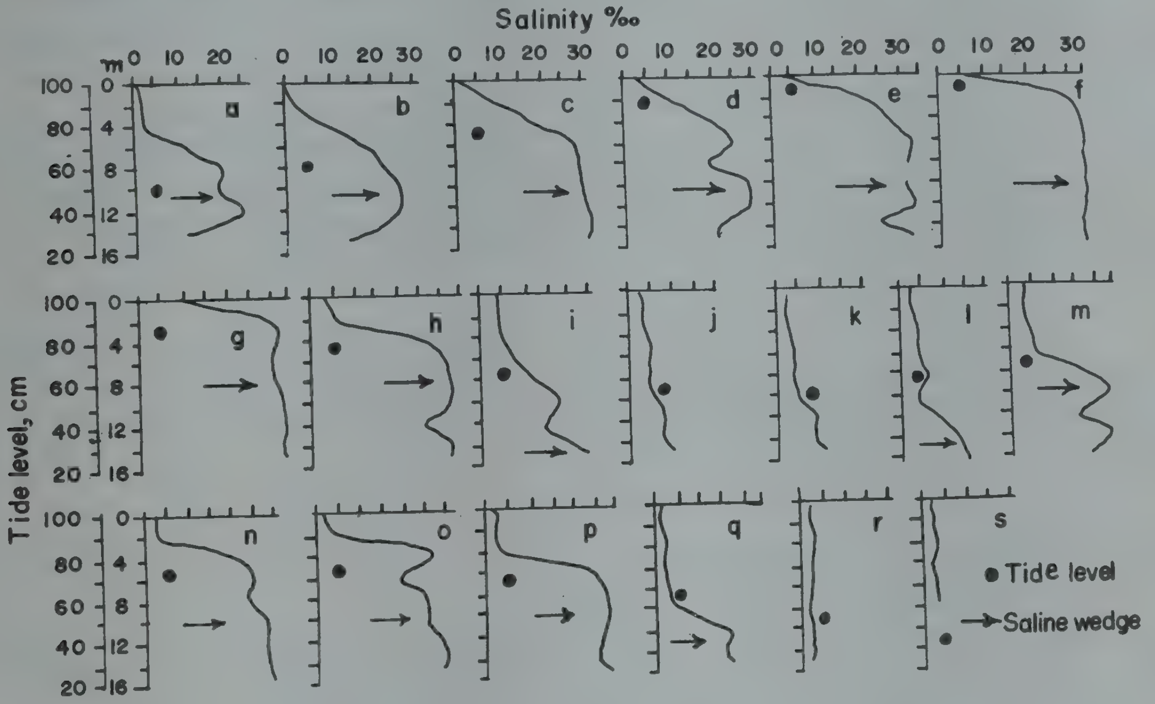
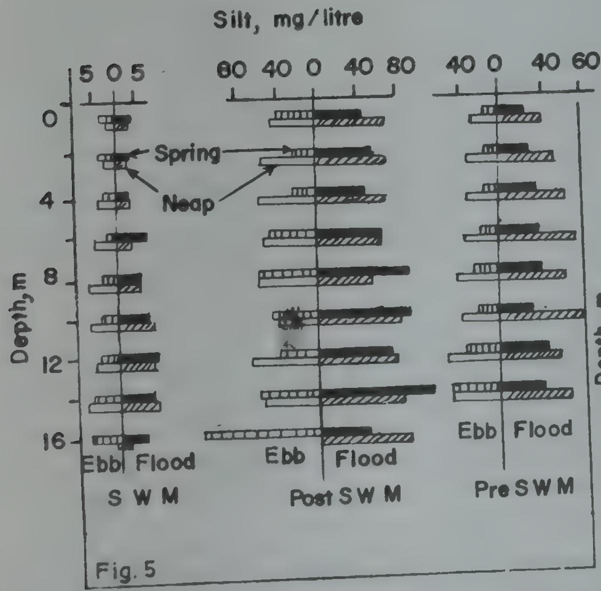
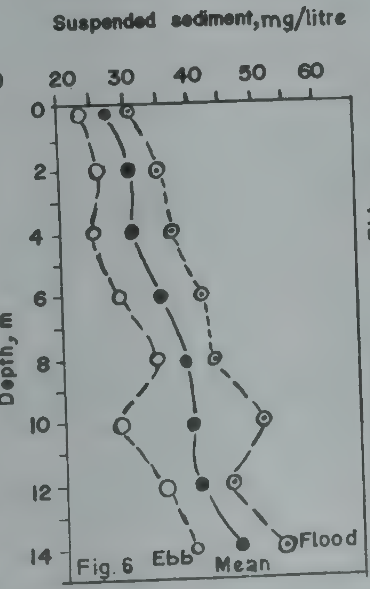


Fig. 4—Diurnal vertical salinity variation during spring tide 24 to 25 July 1975 at station B [Time (hrs): a, 0930; b, 1010; c, 1115; d, 1200; e, 1330; f, 1410; g, 1515; h, 1610; i, 1705; j, 1800; k, 1900; l, 2100; m, 2200; n, 2325; o, 0010; p, 0200; q, 0300; r, 0405; s, 0655]





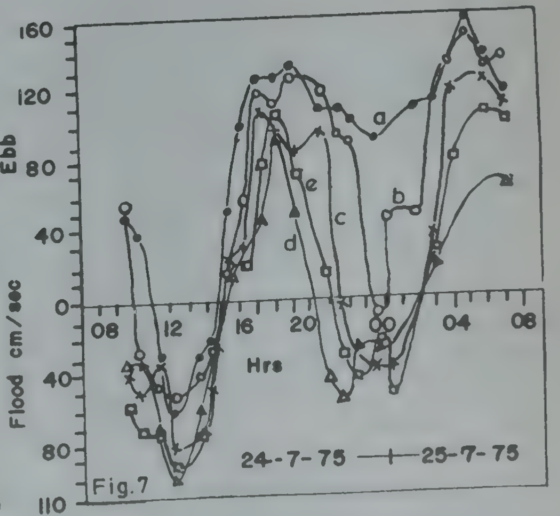


Fig. 5—Average silt content at different depths for ebb and flood of spring and neap tides during SW monsoon, pre and post SW monsoon seasons at station B. Fig. 6—Vertical variation of the annual mean suspended sediment concentration at station B. Fig. 7—Diurnal variation of current at station B [Depth (m): a, 0; b, 4; c, 8; d, 12; e, bottom]

postmonsoon season at the surface but in general the surface current velocities are higher during the monsoon season compared to post and premonsoon periods. Highest velocities observed in the monsoon and premonsoon seasons are 157 and 128 cm/sec respectively.

Diurnal variations of current in the vertical at hourly intervals during the spring tide 24-25 July 1975 (monsoon) and at neap tide on 5-6 February 1976 (premonsoon) are shown in Figs 8 and 9 respectively. Monsoon observations show that the surface and bottom currents are in opposite direction persisting for a few hours during rising or falling tides and the magnitudes of this 2 layer flow at particular times are as much as 120 cm/sec ebb current near surface and 40 cm/sec flood current near bottom. At the end of the flood current, ebb current can be seen throughout the entire depth of the inlet, whereas at the end of the ebb current, flood current begins first near the bottom of the inlet and then gradually extends up to a depth of about 4 m from the surface. Fast changes in the speed of the current with time are also evident.

Sequence of neap tide current changes in the premonsoon season does not show 2 layer flow with rising or falling tides. It also shows that the reversal of current occurs as the tide changes in the entire layer from surface to bottom. The velocity gradients of the current with depth are small compared to those of monsoon season.

Per cent total flow down stream—Percentage distribution of flow down stream with depth in the 3 seasons during spring and neap tides is presented in Fig. 10. Above 50% down stream flow indicates predominance of ebb flow over flood flow and below 50% indicates the predominance of flood flow over ebb flow. Percentage distribution of flow down stream depends on the intensity and duration of flood and ebb currents which in turn are effected by the tides and freshwater discharge into the estuary. The flow during the days of observation (Fig. 10) in the monsoon season is predominantly down stream (ebb current). During the postmonsoon season in December 1975 at spring tide, the ebb flow is predominant whereas in February 1976 at neap tide, the flood flow is predominant. In the premonsoon season, both at spring and neap tides, up stream flow is predominant throughout the depth of the inlet. Predominant down stream flow in the monsoon observations is evidently due to the dominant influence of freshwater discharge over the tidal flow. In the premonsoon season the predominant up stream flow is due to dominant influence of the tidal flow.

Tidal prism—Tidal prism for the inlet, i.e. total volume of water exchanged, has been calculated using the average current velocities of the layers, 0-4, 4-8,

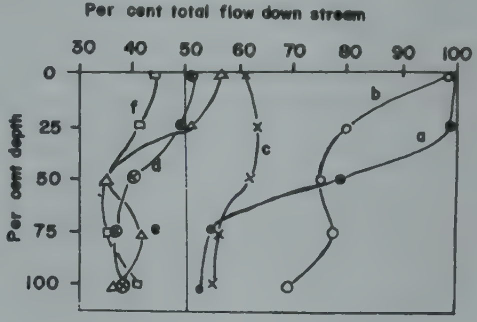


Fig. 10—Vertical distribution of flow in the 3 seasons [a, spring—24 to 25 July 1975; b, neap—31 July to 1 August 1975; c, spring—2 to 3 December 1975; d, neap—5 to 6 February 1976; e, spring—12 to 13 April 1976; and f, neap—21 to 22 April 1976]

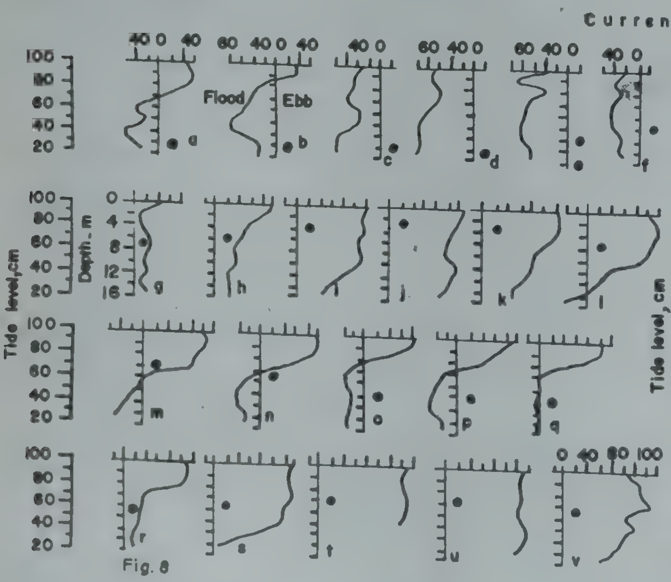


Fig. 8

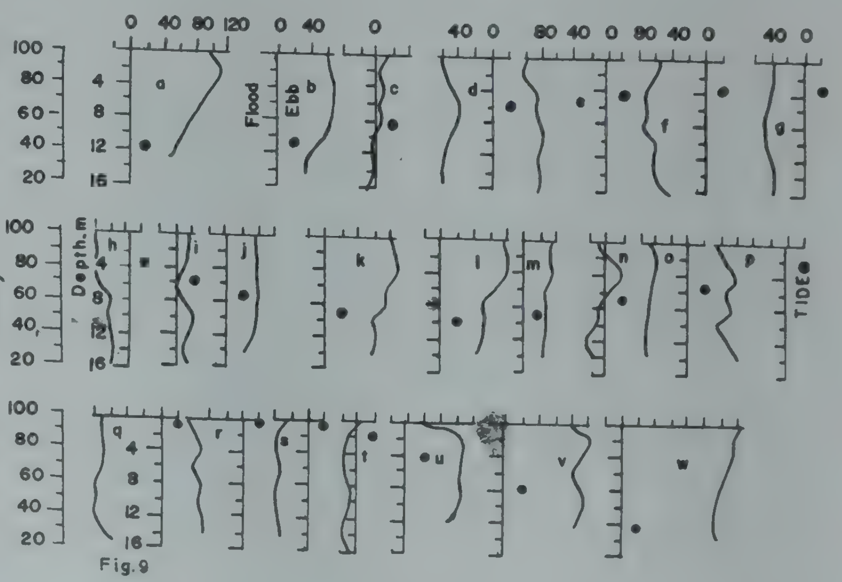


Fig. 9

Fig. 8—Diurnal vertical variation of current during spring tide 24 to 25 July 1975 at station B [Time (hrs): a, 0930; b, 1010; c, 1115; d, 1200; e, 1330; f, 1410; g, 1515; h, 1610; i, 1705; j, 1800; k, 1900; l, 2100; m, 2135; n, 2200; o, 2345; p, 0015; q, 0200; r, 0300; s, 0405; t, 0500; u, 0600; v, 0655]. Fig. 9—Diurnal vertical variation of current during neap tide 5 to 6 February 1976 at station B [Time (hrs): a, 1015; b, 1110; c, 1200; d, 1310; e, 1410; f, 1500; g, 1610; h, 1700; i, 1800; j, 1900; k, 2015; l, 2110; m, 2200; n, 2300; o, 0000; p, 0100; q, 0210; r, 0300; s, 0400; t, 0500; u, 0600; v, 0700; w, 0900]

8-12 and 12 m to bottom and the respective cross sectional areas. Spring tide periods are chosen to get the maximum possible values of tidal prism for flood and ebb tides in the 3 seasons. The average tidal prism for the spring tide in the premonsoon season is $31.5 \times 10^6 m^3$ (35.3×10^6 for flood and 27.7×10^6 for ebb). The freshwater inflow into the backwaters is least in this season and consequently the down stream flow of low salinity water in the inlet is small. The effect of freshwater inflow on the tidal prism during monsoon and postmonsoon seasons is very significant. Tidal prism values range between 9.5×10^6 and $83 \times 10^6 m^3$ for flood and 27.7×10^6 and $132.6 \times 10^6 m^3$ for ebb tide. These values represent the order of magnitude and considerable variations occur depending on the tidal range and duration, quantity of freshwater discharge into the estuary, intrusion of saline wedge, etc.

Stability of the inlet—While considering the stability of the inlet, changes in the location of the inlet itself and changes in its cross sectional area are to be considered. If N represents total rate of transport of sediment through the bed load as well as suspended sediment load across the inlet, taking the direction of ebb flow as positive X direction, the condition for stability of the inlet cross section over a period of time t is

$$\int_0^t \frac{\partial N}{\partial x} dt = 0$$

if $\int_0^t \frac{\partial N}{\partial x} dt > 0$ erosion of inlet occurs, and

if $\int_0^t \frac{\partial N}{\partial x} dt < 0$ deposition at inlet occurs.

As seen from the survey charts of the Cochin Port, the inlet has remained practically in its present location for the last few decades and so appears to have location stability. As the location stability of an inlet is likely to be altered mainly through major changes in the channel orientation, the inlet may have location stability as long as the orientation of the outer and inner approach channels is not tampered with.

The inlet has not been dredged as the need for it in the context of safe navigation has not arisen so far. The high tidal current velocities near the bottom appear to sweep the bottom and no net sediment accumulation is taking place at the central part of the inlet.

According to Bruun and Gerritsen[13], cross sectional stability of an inlet may be altered by any or a combination of the factors: (i) prolongation of inlet channel; (ii) abnormal deposition of littoral drift material during severe cyclones; (iii) splitting of main inlet channel into 2 or more channels; and (iv) changes in the bay area from which water flows into the inlet—construction of dams or reclamation of land by constructing bunds, etc.

In respect of the Cochin Harbour inlet, items i to iii are not important as the prolongation of the inlet channel or bifurcation of it can be ruled out for obvious reasons and the abnormal deposition of littoral drift material also may not be expected as the few cyclones that reach this part of the coastline usually loose their severity. Therefore, the most important factor to be considered is the man-made causes like construction of dams and reclamation of land from backwaters. The reduction in bay volume leads to reduced volume exchange through the inlet over a tidal cycle and consequent reduced maximum velocities of the tidal current.

The Thanneermukkam Bund construction has been completed a few years back separating the Vembanad Lake with the rest of the backwaters. The flow through the bund is controlled and the intrusion of saline water into the Vembanad Lake during the premonsoon season is prevented, thereby reducing the bay area for tidal flow. In the monsoon and postmonsoon seasons the flood water of the Vembanad Lake is allowed to pass through the bund. Therefore, the effect of Thanneermukkam Bund on the Cochin Harbour is mainly on the reduction of flow through the inlet in the premonsoon season which results in reduced maximum tidal velocities that can cause increased sedimentation rates in the harbour area. Considerable amount of siltation occurring in the outer channel at a distance of 1800 m from the inlet has been reported earlier[14]. It is important for the Cochin Harbour to assess the sedimentation rates in the harbour, study the bed load movement at the inlet and watch for shoaling area so as to connect the cause and effect, if any.

Acknowledgement

The authors are grateful to the authorities of Cochin Port Trust for sponsoring the Cochin Harbour Project survey during which these data are collected. They express their sincere gratitude to Dr S.Z. Qasim, Director and to Dr T.S.S. Rao, Scientist-in-Charge, for their interest and encouragement. Thanks are due to their colleagues at the Regional Centre for collection of part of the hydrographic data. Thanks are also due to Dr J.S. Sastry for going through the manuscript and offering valuable suggestions.

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Coccoliths from Sediments of the Gulf of Kutch

M V SHANKARANARAYANA GUPTHA

National Institute of Oceanography, Dona Paula, Goa 403 004

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Sediment samples (31) from the Gulf and adjacent continental shelf have been studied for the distribution of coccoliths. Ten modern and 42 reworked coccoliths of Upper Cretaceous and Lower Tertiary have been encountered. The Gulf shows predominance of reworked fossils indicating very slow deposition. Sediments of the adjacent shelf show that the northern part is almost devoid of modern flora except for traces of *Gephyrocapsa oceanica* and a few reworked fossils while sediments on the shelf off the mouth of Gulf reveal gradual increase and decrease of modern and reworked coccoliths respectively with increasing depth. Sediments of the 4th transect towards southern end of Gulf indicate increase in the modern flora both in diversity and abundance and decrease in reworked fossils seaward. It is inferred that the Gulf is the main source of reworked fossils in the slope and perhaps in the deeper regions.

The Gulf of Kutch is one of the least explored areas on the western coast of India. Petrographic and foraminiferal aspects of rocks obtained from a water depth of 60m from the Gulf indicate them to be calcareous sandstones formed in an intertidal environment[1]. Further studies on grain size and coarse fraction indicate that the high tidal velocities (2-5 knots) exercise considerable influence on the sedimentary processes[2]. The important finding is that the high tidal currents act as a hydraulic barrier on the continental shelf of the Gulf of Kutch such that the sediment transported from the Indus is apparently prevented from being transported southward along the Saurastra shelf. Further, it is inferred on the basis of the distribution of mica in the sediments that the sediments are carried out of the Gulf by the tidal currents bypassing the continental shelf and are deposited on the continental slope[2]. Geochemical studies confirm these sedimentary processes[3]. Studies on organic carbon pattern and foraminiferal assemblage have also been made[4].

In the present investigation, distribution of coccoliths in sediments samples from both the Gulf and adjacent continental shelf (Fig. 1) has been studied.

Geology of the Area

The gulf is bounded on the south by the Deccan traps which are found in the Saurastra Peninsula. On the northern side in the interior of Kutch area a complete series starting from Jurassic to Pleistocene is found. The Jurassic rocks occupy a large area and are bordered successively by Deccan Traps and Tertiary rocks which extend to the coast and have dips towards the south and southwest[5].

Materials and Methods

During the reconnaissance survey of the Gulf of Kutch by *RV Gaveshani* during its 2nd cruise (February-March 1976), a number of sediment samples were collected. Owing to the rocky bottom, out of 26 stations, there was no recovery from 6 stations and at 5 stations small quantities of rock and

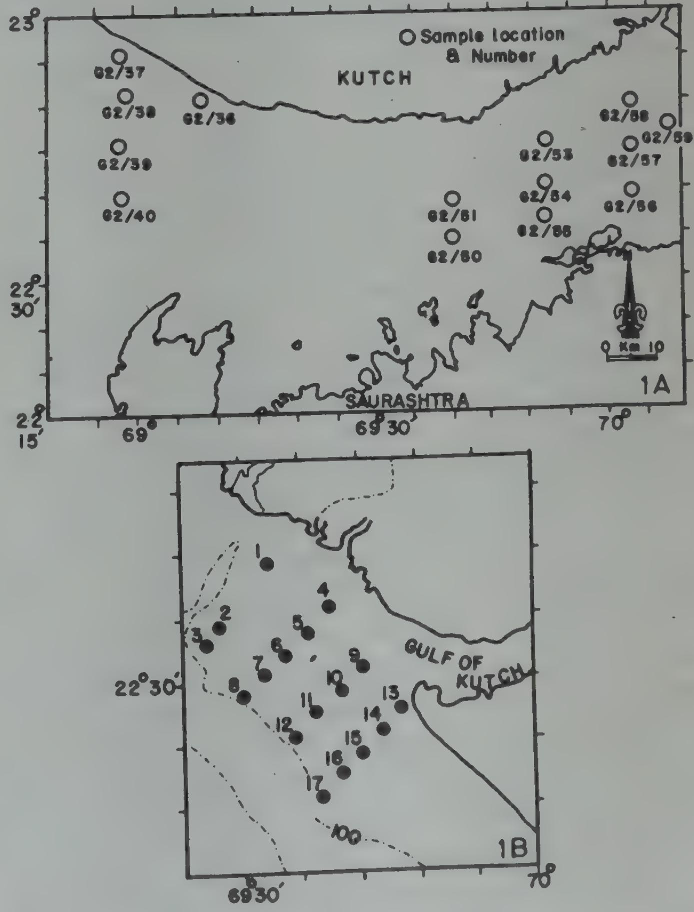

Fig. 1—Station locations (A) in the Gulf of Kutch and (B) in the adjacent continental shelf

coral fragments were obtained. In the present investigation, 14 grab samples from the Gulf have been utilized for the study on coccoliths and their distribution (Fig. 1A). Besides, in order to make a comparative study, 17 samples from the continental shelf region adjacent to the Gulf have also been examined (Fig. 1B).

Smear slides were prepared and scanned at a magnification of 1000 and 1500X through Reichert polarising microscope and their relative abundance estimated, following the method by Boudreaux[6]. Identification of coccoliths was made from the available literature[7-11].

Results and Discussion

Fig. 2 shows that 42 reworked and 10 modern coccolithophoriid species are present in the sediment samples. Sediments in the Gulf are generally poor in coccoliths and furthermore reworked ones predominate over the modern flora. These fossil coccolithophoriids range in age from Upper Cretaceous to Lower Tertiary. Out of 14 samples in the Gulf, 2 samples from sts 57 and 59 in the eastern part of the Gulf exhibit anomalous distributional pattern. They show a dominance of modern flora and much greater diversity. Except at sts 57 and 59, the samples at other stations contain reworked coccoliths in varying diversity from station to station with a few modern forms. Among reworked ones, *Watznaueria barnesae* is found in both the Gulf and shelf samples. It is, however, common in the Gulf but rare in the shelf sediments.

On the other hand, on the shelf adjacent to mouth of the Gulf, the distribution of coccoliths is very sporadic. Stations 1-3 on the traverse across the shelf to the northern side of the Gulf show that they are devoid of any modern flora except for traces of *Gephyrocapsa oceanica*, a modern form, and a few reworked fossils. Further south of the above in a transect of 5 stations (sts 4-8) it is observed that the reworked fossil forms become rare and there is a seaward increase in modern ones with none in the inner shelf samples to 4 species in the outer shelf samples. The 3rd transect of stations (sts 9-12) also exhibit similar distributional pattern. The 4th transect of stations (sts 13-17) south of the Gulf of Kutch show somewhat different distributional pattern with a decrease of reworked fossils and seaward increase of modern coccolithophoriids both in diversity and abundance. Earlier studies[12] on coccolithophoriids in the sediment on the continental shelf off Saurashtra coast, south of the Gulf of Kutch, have shown the presence of the following: *Emiliania huxleyi, Gephyrocapsa oceanica, G. caribbeanica, G. aperta, Coccolithus pelagicus, Braarudosphaera bigelowi, Cyclococcolithus leptoporous, Umbellosphaera tenuis, Umbilicosphaera mirabilis, Rhabdosphaera clavigera, R. stylifera, Ceratolithus cristatus, C. telesmus, Helicopontosphaera kamptneri, Anoplosolenia brasiliensis, Scapholithus fossilis, Pontosphaera sp., Thoracosphaera sp.*, and *Ericsonia sp.*

Based on the study of a deep-sea core from the western continental slope off Bombay[13] 18 modern species along with 8 reworked fossils such as *Scapholithus fossilis, Arkhangelskiella cymbiformis, Watznaueria barnesae, Micuala staurophora, Nannoconus sp., Discoaster brouweri, D. perplexus*, and *D. variabilis*, have been reported.

From the distributional pattern of the coccolithophoriids in the sediments of the Gulf and the continental shelf, the following inferences are drawn: (1) The source of the as many as 42 species of reworked fossils is within the Gulf. They may represent forms which have been derived from the erosion by tidal currents of upper Cretaceous and Lower Tertiary rocks in the Gulf. (2) Presence of more reworked fossils compared to the modern one in the Gulf sediment suggests very slow deposition. (3) General absence of reworked forms on the continental shelf south of the Gulf of Kutch may be due to the tidal (hydraulic) barrier concept proposed[2] to explain the distribution of mica in that region. The reworked forms are similarly prevented from southward transport while they are carried out of the Gulf by the high velocity tidal currents. (4) The presence of reworked forms in the sediment on the continental slope at a depth of 2240m off Bombay[13] and in the deep-sea sediments[14] further southwest of Laccadives ridge at a depth of about 4583m indicates that from a source in the Gulf they are transported southward in the deeper waters of the continental slope with a decreasing trend in abundance southward. The southward transport could probably take place under the action of southwest monsoon current. Fig. 3 shows in a schematic manner the probable direction of transport of the reworked forms. It is, therefore, possible that these reworked biota are carried by currents owing to their minute size and even mild currents would accomplish the transportation.

Heye[15] on the basis of the magnetization of sediment cores from the Indian Ocean, has stated that all the measured cores of the continental slope of the west coast of India show similar character of their magnetization inspite of the greater distances (up to 2000 km) and the cores lying only little more towards the ocean do not show such variations. For the first group, it is suggested that a strong coast-parallel influence possibly by currents is the cause.

It is conjectured that the Indus and the Narmada rivers are sources of reworked fossils in the continental slope region off Bombay[13]. From the present study it is

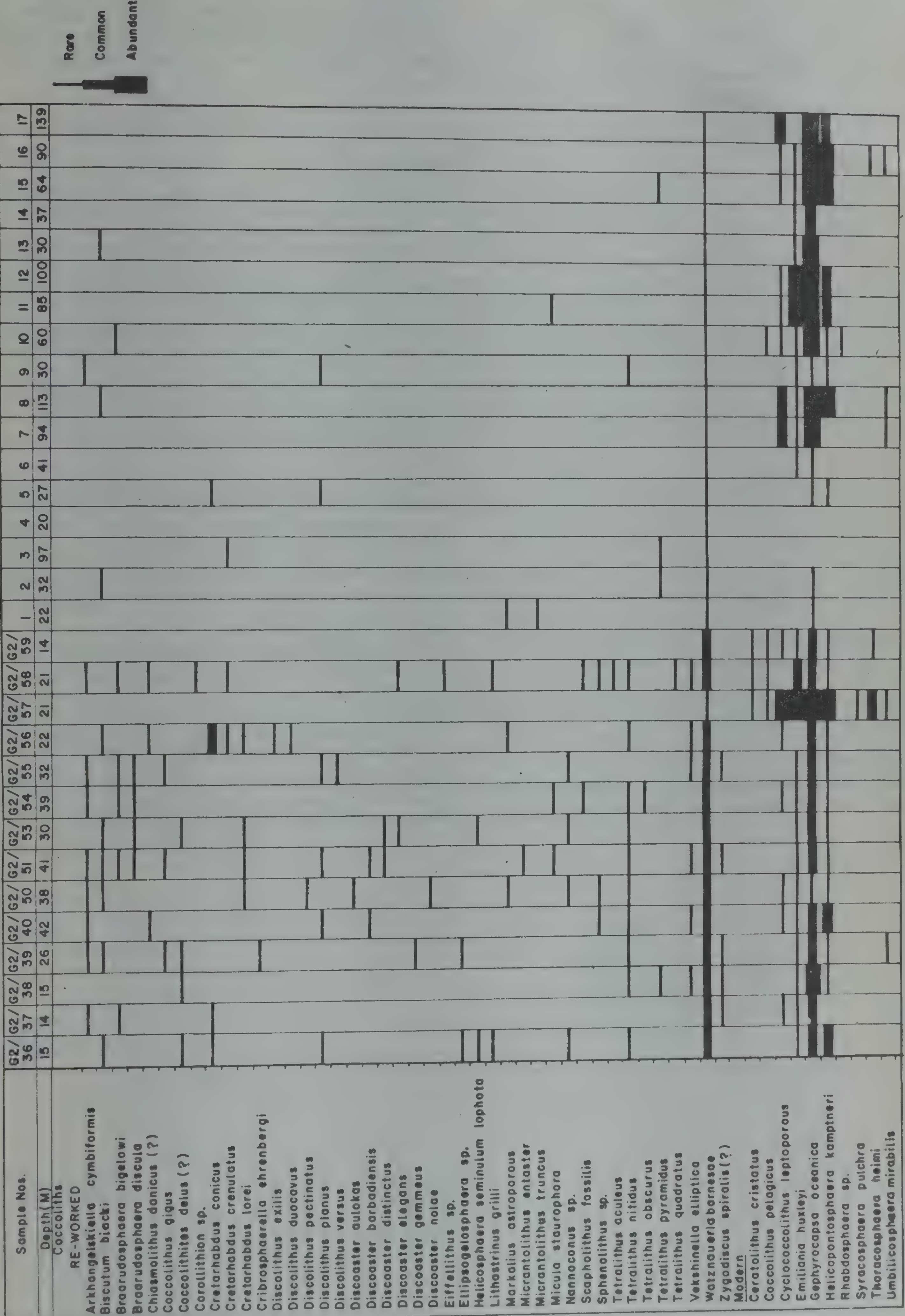

Fig. 2—Distribution of coccoliths inside and outside the Gulf of Kutch

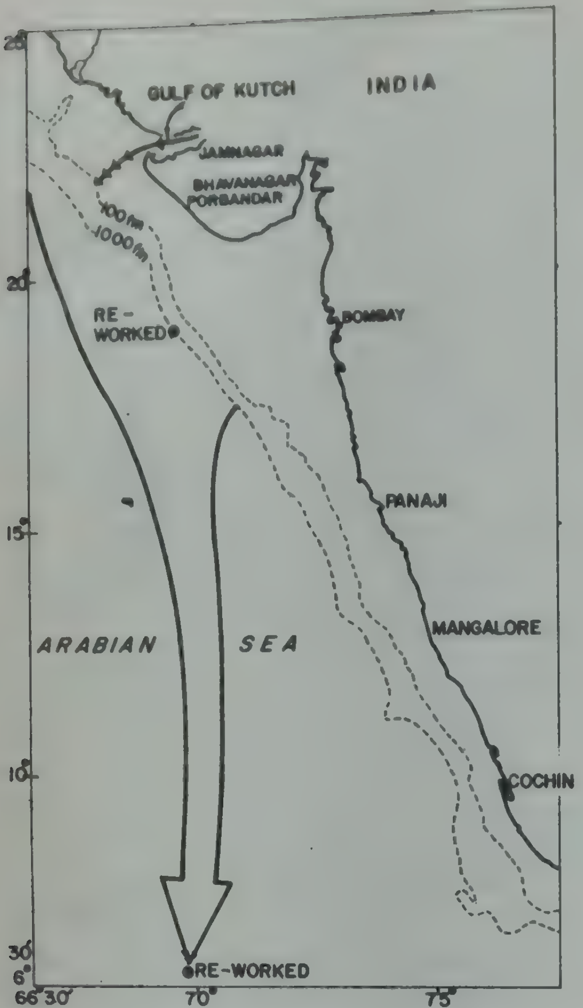

Fig. 3—Schematic diagram showing the probable direction of transport of reworked fossils

apparent that the Gulf also plays a prominent role in supplying the reworked fossils.

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Succession of Organisms Following *Trichodesmium* Phenomenon

V P DEVASSY, P M A BHATTATHIRI & S Z QASIM
National Institute of Oceanography, Dona Paula, Goa 403004

Received 1 *February* 1979

Enrichment caused by *Trichodesmium* phenomenon is manifested in the environment by the appearance of a series of organisms in succession. In April and May, when *Trichodesmium* bloom is on the decline in Goa waters (Arabian Sea) and the sea conditions are still fairly uniform, a mixed diatom bloom comprising largely of *Chaetoceros* appears. This is followed by swarms of cladocerans mostly consisting of *Evadne*. Soon afterwards the cladocerans are succeeded by dinoflagellates and green algae. At this stage, *Noctiluca* becomes the most predominant organism. The dinoflagellates are soon followed by swarms of copepods and finally the carnivores (siphonophores and *Sagitta*) make their appearance in large numbers. Thus, within 2 months, concommittent with the decline of *Trichodesmium* bloom, rapid changes occur in the population density of planktonic life of the sea when one set of organisms gets replaced by another and each time the community gets reorganized.

In a recent communication, the occurrence of *Trichodesmium* phenomenon in the coastal waters of Goa (Arabian Sea) has been reported[1]. This phenomenon occurs in the form of thick blooms of the blue-green alga *Trichodesmium erythraeum* at a time when the sea is calm and has fairly uniform conditions of temperature and salinity. The interesting features of this phenomenon are the intermittent appearance and disappearance of the bloom which is mainly confined to the surface, the annual periodicity of the bloom from February to May, the colour to the water it imparts, the enrichment to the sea it gives and the growth of other organisms it promotes[1]. This communication gives details of community succession occurring in the nearshore waters of Goa during the period when the bloom was declining.

Succession occurs when the environmental conditions become exceptionally favourable for certain organisms to appear in abundance. Thus the fairly rapid or abrupt changes occurring in the environment are associated with the abundance of one organism or a group of organisms replacing the others. According to Smyada[2], environmental disturbances produce changes in many growth variables upsetting the previous equilibrium and leading the community to reorganize itself.

Materials and Methods

The period of study was from April to May 1977 when the *Trichodesmium* phenomenon was declining. An area was selected in the sea, beyond 10 m depth, where the bloom was in profusion earlier (Fig. 1) and this site was worked 7 times in quick succession at intervals of 3 to 12 days. Water samples were collected from 0, 2, 5 and 10 m depths. Temperature, salinity, dissolved oxygen, inorganic PO_4-P, NO_3-N, NO_2-N were measured along with ^{14}C uptake, particulate organic carbon (POC), chlorophyll *a*, pheopigments, cell counts and zooplankton biomass and composition.

An HT net (0.22 mm mesh width) provided with a flow meter was used for the horizontal zooplankton hauls from the surface. The biomass was expressed as ml/m^3. ^{14}C uptake was studied by the procedure reported earlier[1]. For phytoplankton counts, 500 ml of water sample was collected and fixed in Lugol's iodine and preserved in 3% formalin.

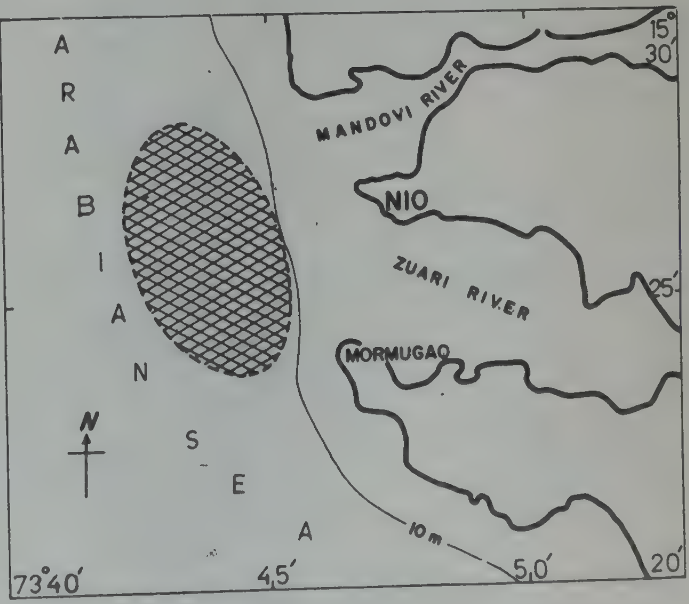


Fig. 1—Goa coast where *Trichodesmium* phenomenon occurs every year [Shaded region shows area where observations were made during April and May 1977 on community succession]

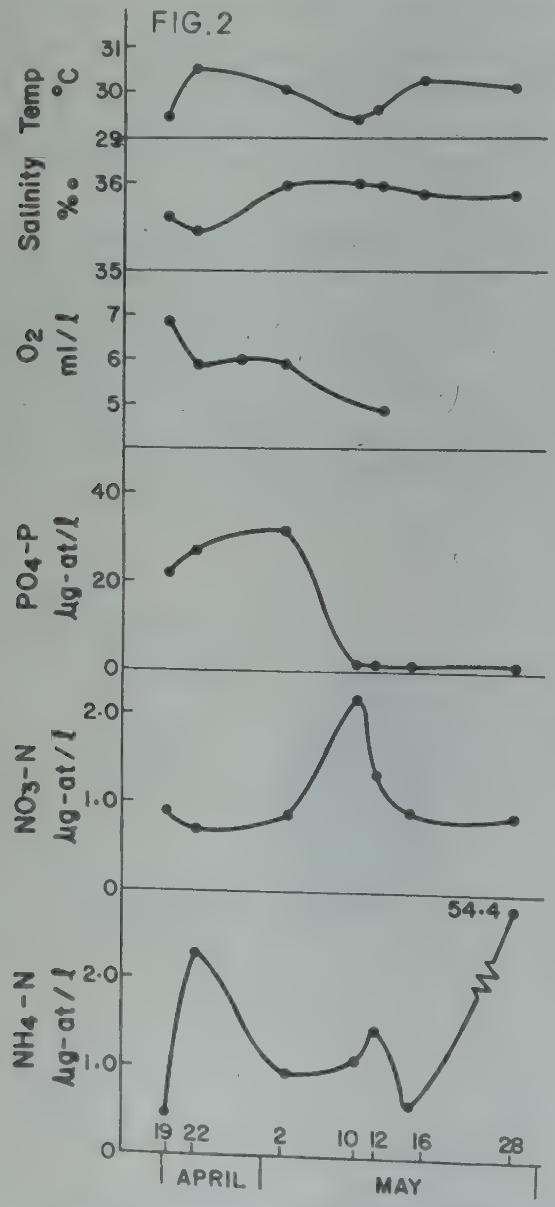
Results and Discussion

Some of the environmental features during the period of study are shown in Fig. 2. Both temperature and salinity increased in April and May while dissolved oxygen showed a decline. The decline in oxygen may be because the bloom was decaying. From the values of PO_4-P, NO_3-N and NH_4-N which remained high in April and early part of May (Fig. 2), the enrichment of the environment is clearly evident. Towards the end of May, PO_4-P values became very low while NO_3-N and NH_4-N showed peaks when *Trichodesmium* was decaying.

Fig. 3 gives the values of particulate organic carbon, ^{14}C uptake, chlorophyll *a* and pheopigments on different days of study. All these were high during the later part of the bloom and showed irregular fluctuations when the bloom was disappearing. However, pheopigments increased considerably when *Trichodesmium* was decaying. Similarly, POC also became high on 28th May which was the last day of observation (Fig. 3).

During the first series of observations which was started on 19th April 1977, a visible change in the colour of water was noticed. This was because of a mixed diatom bloom near the surface comprising largely of *Chaetoceros curvisetus*, *C. lorenzianus*, *C. laciniosus* and other *Chaetoceros* spp (Fig. 4). *C. curvisetus* alone contributed 37.8% of the total phytoplankton counts. Several other diatoms, a few dinoflagellates and green algae were also abundant in addition to blue-green algae (Fig. 4). Samples collected from below the surface at 2, 5 and 10 m depths showed appreciable quantities of *C. curvisetus*—about 34, 45 and 40% of total counts at the 3 depths respectively. Other dominant diatoms were *Ceratulina* sp., *Skeletonema costatum* and *Rhizosolenia* spp. Thus the diatoms alone contributed 95.6, 98.4, 98.2 and 99.6% of the total phytoplankton at 0, 2, 5 and 10 m depths respectively. In the adjacent areas, where bloom was not seen earlier, *Chaetoceros* species were not so abundant.

Three days later, on 22nd April, a cladoceran swarm



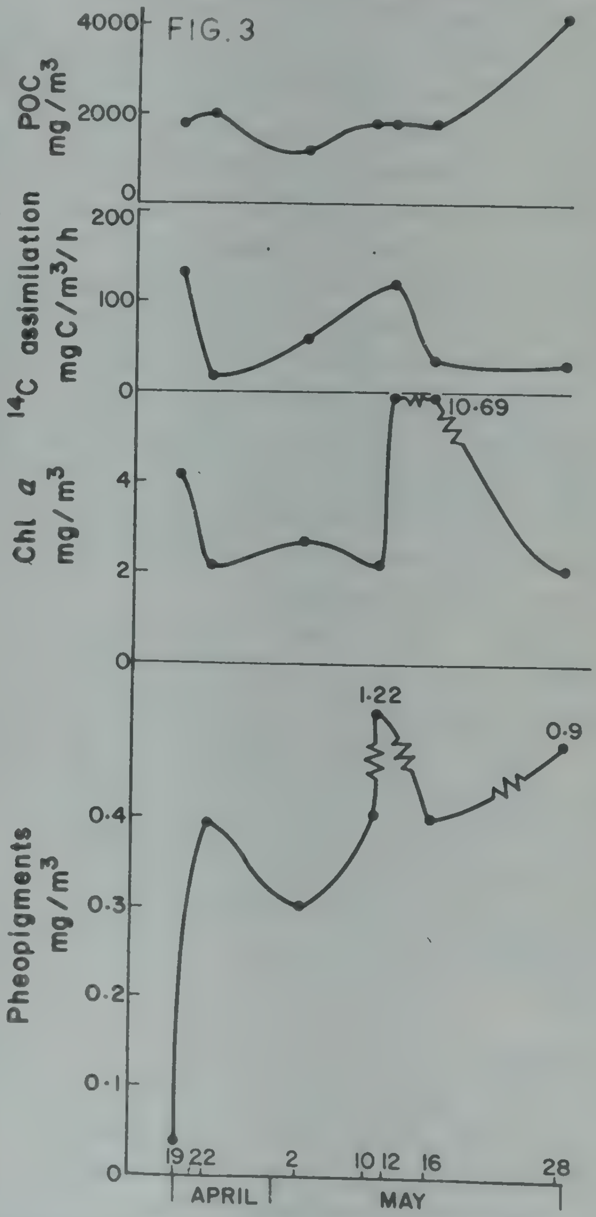


Fig. 2—Physical and chemical features of the area where *Trichodesmium* bloom was declining

Fig. 3—Particulate organic carbon (POC), ^{14}C assimilation, chl *a* and pheopigments at the place of observation

was found at the same place (Fig. 4). The predominant cladoceran was *Evadne tergestina*. Numerically, *Evadne* alone contributed 975/m^3, while all other organisms together constituted only 48/m^3. Copepods with a population of 40/m^3, formed the next abundant group (Fig. 4). At this stage, *Chaetoceros curvisetus* was still present in appreciable numbers in the water column along with the other *Chaetoceros* species. However, in general the phytoplankton population dwindled rapidly presumably as a result of active grazing by the herbivore *Evadne*. Selvakumar[3] noted that when a cladoceran swarm, mainly consisting of

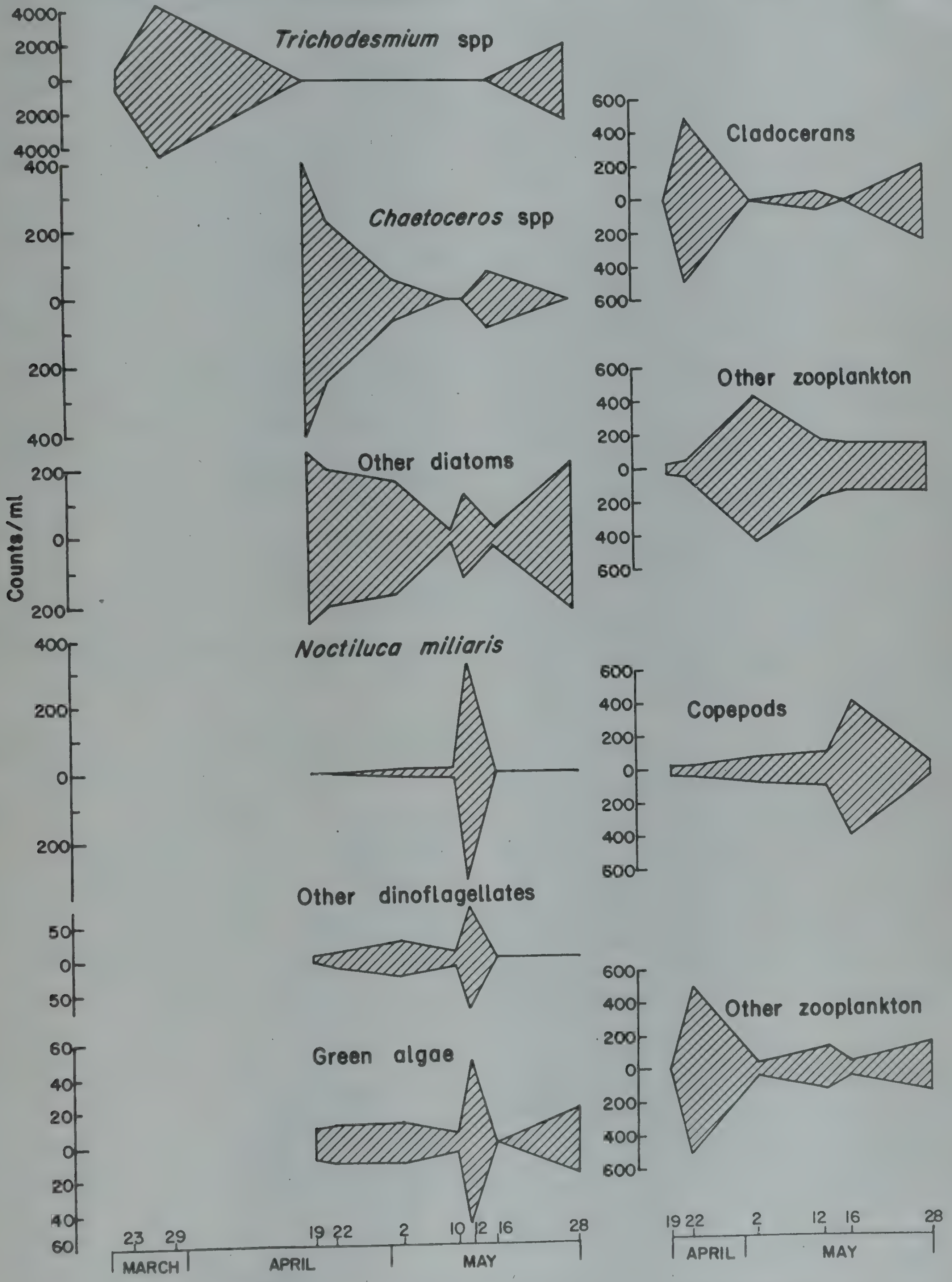


Fig. 4—Succession of organisms following *Trichodesmium* bloom [Topmost figure shows density of *Trichodesmium* bloom from 23 March to 28 May 1977. All other diagrams show abundance of different organisms from 19 April to 28 May 1977]

E tergestina, occurred off Karwar and Goa, the most conspicuous phytoplankton organisms in the environment were diatoms (setoid forms) such as *Chaetoceros, Thalassiothrix* and *Nitzschia* and dinoflagellate *Ceratium*. This indicates a possible association between the cladocerans and diatoms. In the central Arabian Sea, an abundance of *E. tergestina* was earlier found from March to May[4]. In the coastal waters of Madras, maximum abundance of *E. tergestina* from March to May followed the diatom abundance[5]. High PO_4-P value in the water column when cladoceran swarm was recorded may partly be due to these organisms, as phosphorus is known to be exuded by the activity of cladocerans[6].

On 2nd May, diatoms became few and dinoflagellates such as *Peridinium* spp began to appear in large numbers (Fig. 4). At 10 m depth, *Noctiluca miliaris* was also seen. On the 10th May, *Noctiluca* started appearing near the surface (2 m depth) and on 12th May a dense bloom of *Noctiluca miliaris* was observed in the same area (Fig. 4). This alone (640 cells/ml) contributed about 57% of the total phytoplankton population. Besides this, other dinoflagellates such as *Peridinium* spp, *Prorocentrum* spp, *Gymnodinium* sp., *Dinophysis miles* and *Ceratocorys* sp. also became abundant. Other organisms found in large numbers in association with dinoflagellates were green algae (Fig. 4). Diatoms generally were sparse at this time both in the bloom and non-bloom areas. Thus it is clear that dinoflagellates and green algae succeeded diatoms in their abundance. In other words, some kind of preconditioning of water was done before dinoflagellate bloom appeared[7].

On 16th May, the *Noctiluca* bloom was followed by swarms of copepods which formed about 95% of the total zooplankton population (Fig. 4). *Acrocalanus gracilis* (246/m^3), *A. monachus* (236/m^3) and *Acartia erythraea* (147/m^3) were the most dominant species. These copepods are known to be herbivorous[8,9]. Dinoflagellate population starts dwindling probably because of intense grazing of these herbivores on them. At this time, *Chaetoceros* sp. was still present, while the other phytoplankton organisms became sparse (Fig. 4).

on 28th May, a dense *Trichodesmium* bloom was again seen in coastal waters (Fig. 4) and close to the site where the diatom and dinoflagellate blooms were seen earlier, a swarm of gelatinous organisms was observed (Table 1). Siphonophores (0.074 ml/m^3) and chaetognaths (0.025 ml/m^3) formed an appreciable part of the biomass. However, numerically *Evadne tergestina* (21/m^3) was still the most dominant species. Chaetognaths comprised *Sagitta enflata, S. robusta* and *S. bedoti*. Of these, *S. enflata* was most abundant (Table 1).

Total zooplankton biomass for the period of observation is shown in Fig. 5. Towards the end of April, when *Trichodesmium* bloom was declining, zooplankton biomass attained its first peak. This was largely contributed by cladocerans. In early and mid May, copepods largely contributed towards the second peak (Fig. 5) and their abundance kept fluctuating till carnivores begin to predominate. Towards the end of May, the highest biomass (Fig. 5) recorded was largely contributed by the carnivorous gelatinous forms (Table 1).

In a marine community, organisms are distributed according to the position they occupy in their trophic chain. The animals which occupy higher trophic level have a wider distribution in space and time from the areas of enrichment in the sea[10]. The present investigations seem to support this concept of ecology as the series of community succession which appeared in Goa waters was well marked. The phytoplankton blooms were followed by swarming of herbivores and finally the community ended up in a greater abundance of carnivores which were widely dispersed and occupied a much larger area. Siphonophores and chaetognaths appeared later and their population maxima was attained after a time-lag of about 4 months from the initial appearance of *Trichodesmium* bloom. Community succession, therefore, was probably a result of the interaction between different environmental factors which induced biological interrelationship and population explosion of certain organisms. This, in all probability, was due to

Table 1—Zooplankton Composition during the Swarm of Gelatinous Forms Seen on 28.5.77

	counts/m^3		counts/m^3
Siphonophores	93	Polychaetes	1
Sagitta enflata	18	*Cresets acicula*	1.2
Sagitta robusta	0.12	Ostracods	0.12
Sagitta bedoti	0.12	Appendicularians	0.04
Evadne tergestina	210	Cirripeds	0.12
Copepods	36	Other larval decapods	0.12
Lucifers	1	Lamellibranchs	2

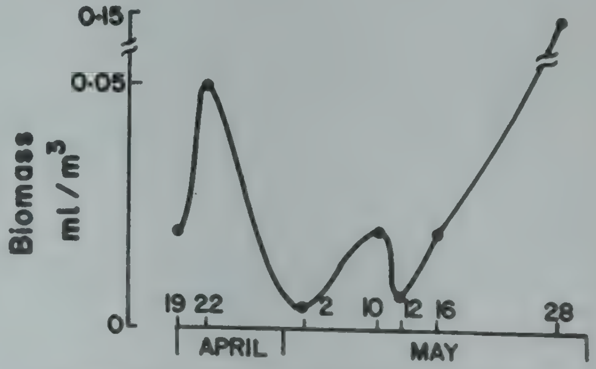


Fig. 5—Zooplankton biomass during April and May when *Trichodesmium* bloom was declining

Trichodesmium phenomenon which produced enrichment and promoted the growth of certain sets of organisms one after the other.

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Incidence of Red Water Along South Kerala Coast

P VENUGOPAL, P HARIDAS, M MADHUPRATAP* & T S S RAO*
National Institute of Oceanography, Regional Centre, Cochin 682018

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Incidence of red water along the Kerala coast at 2 localities, off Quilon and Cochin, in August 1976 and 1977 is reported. High concentrations of *Noctiluca miliaris* (up to $7.71 \times 10^5/m^3$ in 1977) are associated with these occurrences. They completely dominate the plankton community contributing >90% of the numbers. High production of diatoms initiated by nutrient-rich and fairly high saline upwelled waters appears to cause the bloom of the dinoflagellate *Noctiluca*.

Occurrence of discoloured water associated with the blooms of certain planktonic species, referred to as red water or red tide has been reported from many parts of the world. It is common in the productive tropical and subtropical areas, where the turn over rates of organic matter are very high, but is rare in the high latitudes. Some of the causative species of red water produce toxic substances, but the toxins get dissipated quickly. Under special circumstances, however, these organisms and toxins they produce become abundant and if this situation persists mass mortalities of fish and other organisms may occur. The events that lead to the formation of red tides usually escape detection so that their sequence is not clearly understood.

Along the Indian coast, there are several reports on *Trichodesmium* blooms[1-3]. Among dinoflagellates, *Noctiluca, Gonyaulax, Gymnodinium, Peridinium* and *Conchlodenium* are known to be associated with outbreaks of red water[4-6]. Incidence of red water off Cochin and Quilon associated with swarming of *Noctiluca miliaris* is reported here.

Materials and Methods

Discoloured water was found to enter the Cochin harbour area (09° 30′N, 76° 15′E), through the mouth of the estuary during high tide. This brownish red water was present for a week (12.8.77 to 18.8.77). The intensity of discoloration weakened on 16.8.77 but increased again by 18.8.77, whereafter it disappeared. Red water associated with large numbers of *Noctiluca* was also observed on 17.8.1976, off Quilon and Cochin.

Three stations, one in the outer channel at fairway buoy (st 1) in the sea and 2 stations at the exit of Matancherry (st 2) and Ernakulam (st 3) channels at the mouth of Cochin backwaters (st 2 and 3 about 7 km away from st 1) were sampled during the week. Water samples were collected at the surface, mid-depth and near the bottom; plankton samples were collected by a fine meshed HT net (65 μ) provided with a flow meter, in subsurface horizontal tows. Visible transparency depths were measured using Secchi disc. Temperature, salinity and oxygen at different depths, at these stations were also recorded.

Surface water samples were allowed to settle in a sedimentation chamber and cell counts were taken after decanting the supernatant. Chlorophyll *a* estimations were made according to the method recommended[7]. Estimations of inorganic PO_4-P[8], NO_2-N[9] and NO_3-N[10,11] were done. Counts from plankton samples were converted into numbers/m³ using flowmeter data. Coefficient of community[12] (cc) and percentage of similarity of community[13] (PSc) were calculated from the above data to estimate the affinity between samples. A single set of plankton samples were taken off Quilon and Cochin in August 1976, using HT net.

Results and Discussion

Phytoplankton cell counts (numbers/litre) during the period of observation are given in Table 1. The community was dominated by diatoms and the bulk of standing stock was contributed by 4 to 5 species only. Total cell counts were high and ranged from 1.25×10^5 to 6.05×10^5/litre. Earlier studies[14-17] showed dominance of diatoms in the phytoplankton community during this season. Surface chlorophyll *a* values ranged between 18 and 35 mg/m³ which agreed fairly well with the reported values for this month[15]. Considering the contribution of nannoplankton, which is known to be considerable in these waters, the amount of primary organic matter available to the

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*Present address: National Institute of Oceanography, Dona Paula, Goa 403004

Table 1—Phytoplankton Cell Counts (Numbers/Litre)

Species	12.8.77			16.8.77			18.8.77	
	St 1	St 2	St 3	St 1	St 2	St 3	St 1	St 2
Ceratium bergonsii	50,000	+	15,000	–	2,500	5,000	+	5,000
Coscinodiscus marginatus	–	+	–	–	5,000	50,000	–	–
Coscinodiscus sp.	50,000	+	+	–	2,500	–	+	–
Pleurosigma elongatum	55,000	–	–	–	–	–	–	–
P. normanii	–	–	–	–	5,000	50,000	–	–
Nitzchia sigma	52,000	–	–	–	+	–	+	–
N. longisima	50,000	+	+	50,000	2,500	20,000	1,50,000	+
N. closterium	–	50,000	–	–	–	–	50,000	–
Bidulphia sinensis	–	–	–	–	–	–	50,000	–
Bidulphia sp.	–	50,000	–	–	–	–	–	–
Trichodesmium sp.	–	–	–	–	–	50,000	–	–
Skeletonema costatum	–	+	2,00,000	1,10,000	17,500	–	3,00,000	5,50,000
Rhabdonema sp.	+	+	+	+	3,000	+	–	+
Chaetoceros sp.	+	+	–	+	2,500	–	–	–
Thalassionema sp.	–	–	–	10,000	–	–	–	–
Asterionema sp.	–	–	–	–	+	–	–	–
Navicula sp.	58,000	1,50,000	–	50,000	–	–	50,000	50,000

+, Present; –, absent

grazers, would be much higher than what would appear in Table 1.

An interesting feature observed was the total absence of *Noctiluca* in the comparatively low saline surface layer of the water column; the species was collected only in the plankton tows from 1 to 2 m below the surface. *Noctiluca* which is able to some extent select and maintain its position in the water column[18] seemed to prefer higher saline subsurface layers.

Biomass of zooplankton was very high (1.8-4 ml/m^3). *Noctiluca* dominated the catch and contributed to >90% of the numbers. Cumulative concentrations of other groups of zooplankton varied between 3900 and 32750/m^3. Zooplankton observed in samples taken from Cochin and Quilon were in good condition and not adversely affected by the *Noctiluca* bloom. *Noctiluca* counts varied from $3.01 \times 10^5 - 7.71 \times 10^5/\text{m}^3$ at Cochin in 1977 and $2.4 \times 10^5 - 4.1 \times 10^5/\text{m}^3$ during 1976 red water at Quilon and Cochin. Values of PSc and cc were consistently high (from 93 to 99 and 50 to 65 respectively) indicating high affinity between samples and also that the same population was being sampled.

Temperature, salinity and σ_t values (Table 2) showed stratified nature of the water column. The cold high saline water found at deeper layers was identified as the upwelled Arabian Sea water, based on its σ_t. Upwelling along the Kerala coast and the intrusion of this upwelled water into the lower reaches of the estuary during this season have previously been reported[19-22]. Measurements made near the surface showed an increase in salinity by 8‰ and a drop in temperature by 2°C within 1 m, showing that the discontinuity was very close to the surface. Fresh water discharged from the estuary during monsoon[20,23] and presence of upwelled water at the subsurface levels contribute towards an increase in vertical stability in the coastal waters. Qasim *et al.*[24] found an increase in primary production during the monsoon season when there was high vertical stability.

The nutrient values were lower compared to the reported figures[22], except in the case of inorganic PO_4-P, which was higher on the first day of observation. The low values of inorganic nutrients and the decreasing trend in their concentrations throughout the period of observation indicated that these were being actively utilized by the fairly large standing stock of phytoplankton.

Dissolved oxygen values were generally low and did not show much variation. While the low values at the bottom and mid depths indicated the presence of upwelled water, those at the surface were probably due to the uptake of oxygen for the break-up of large quantities of organic matter brought down with the river discharge. Low light penetration (Secchi disk depth - 0.33 to 1 m) also indicated high seston content in the water[25]. Kurian[26] observed red water caused by *Noctiluca* in the lower reaches of the Cochin backwaters and reported low surface oxygen values during that period. Aiyar[27] reporting on red water off Madras has suggested that *Noctiluca* blooms deplete dissolved oxygen.

In examining red water caused by the blooming of non-autotrophic, positively buoyant forms like *Noctiluca*, physical factors are perhaps of greater importance in initiating and maintaining the blooms. Comparative abundance of this species in relation to salinity showed its preference to higher salinities, and

Table 2—Hydrographic Data at the Stations on Different Days of Observation

Day (in August 77)	Depth (m)	Temp (°C)	Salinity (‰)	σ_t	Oxygen (ml/l)	PO_4-P (µg at/l)	NO_2-N (µg at/l)	NO_3-N (µg at/l)
				Station 1				
12	0	28.5	26.9	15.5	2.3	6.6	0.4	2.9
	5	24.5	34.7	23.1	2.9	3.9	2.3	2.4
	10	24.1	34.5	23.3	3.6	3.3	2.3	4.2
16	0	25.8	23.8	14.6	2.6	0.9	0.8	1.7
	5	24.3	34.1	22.8	2.6	1.1	1.7	1.9
	10	23.9	34.7	23.5	3.6	2.0	0.9	1.2
18	0	26.8	20.2	12.5	2.4	1.6	0.7	1.3
	5	24.0	26.7	17.5	2.1	4.8	0.2	1.1
	10	23.9	35.1	23.7	1.8	2.5	0.7	0.6
				Station 2				
12	0	27.6	22.3	12.9	2.6	6.9	0.8	2.5
	5	24.0	34.4	23.2	1.3	4.6	1.6	1.9
	10	24.0	33.5	22.6	1.6	2.9	1.6	2.2
16	0	27.6	15.6	7.9	2.6	1.8	1.4	1.9
	5	23.8	24.0	17.6	1.6	2.4	2.5	1.6
	10	23.5	30.9	20.6	2.0	0.9	2.5	1.6
				Station 3				
12	0	29.0	16.0	7.9	3.0	7.9	1.1	5.1
	5	25.2	29.3	19.1	2.3	2.8	1.5	4.0
	10	25.2	34.3	22.8	2.9	4.7	1.2	3.8
16	0	26.7	22.0	12.9	2.0	1.9	1.4	3.1
	5	24.1	34.5	23.3	1.8	1.5	1.7	2.9
	10	23.8	34.5	23.2	2.0	1.2	2.1	1.3
18	0	27.7	20.1	11.2	2.6	4.4	0.8	2.3
	5	24.5	33.6	22.3	1.7	2.7	0.3	0.6
	10	24.5	32.7	21.6	2.5	4.7	0.2	0.5

on all occasions when they were reported to be prolific, the salinity values were between 32 and 35.4‰. Lower salinities at the surface (<26‰) during the present observations, effectively limited their occurrence at the surface. *Noctiluca* counts at the subsurface levels also decreased drastically (30,000 nos./m^3) at st 2 on 16.8.77 where salinity at mid depths was low (24‰) while at st 1 and 3 on the same day they occurred in higher numbers (4×10^5 and 3×10^5/m^3) when salinity values were 34.1 and 34.5‰ respectively. Analyses of field data from the Florida red tide area[18] showed that there is no real abundance of red tide organisms below 30.5‰ of salinity.

Along the southwest coast of India, occurrences of red water are reported between August and November which marks the end of the upwelling period along this coast. Earlier workers have also observed that *Noctiluca* blooms are preceded by rains and diatom maxima. Relationship between dinoflagellate abundance and lack of turbulence which is analogous to increase in vertical stability is well established[28]. High primary production along the southwest coast during the monsoons owing to nutrient enrichment of the waters from upwelling and estuarine discharges probably sets the stage for non-autotrophic forms like *Noctiluca* to bloom. The observations by Sanders[29] that red tides occur in upwelling areas towards the end of upwelling period also point towards the need for some kind of preconditioning of the water by high diatom production before the dinoflagellates are able to bloom. Biological processes ensuing upwelling and nutrient enrichment which may become diterrent to fish and other life in the sea through oxygen depletion and red tide formations have been discussed[30]. They have noted that the period when the red tides are generally reported, September to November, coincides with the end of the upwelling season, when the weather is warmer with far longer hours of sunshine than during monsoon months. The environmental conditions both at Cochin and Quilon are similar during August and the recurring favourable conditions seem to initiate red tides over the years along the southwest coast of India.

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Studies on Fungi from Coastal Waters of Bombay & Goa

JOE D'SOUZA & ALBERT ARAUJO
Centre of Postgraduate Instruction and Research
(University of Bombay), Panaji, Goa
and
A KARANDE
Naval Chemical and Metallurgical Laboratory, Tiger Gate, Bombay 400 001
and
Y M FREITAS
St. Xavier's College, Bombay 400 001

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Fungi were isolated from immersed timber panels, sediments, mangrove vegetation and algae from the brackish waters in Bombay and Goa. Immersed wood harboured a large population of cellulolytic fungi which rendered the wood susceptible to the attack by secondary invaders like the marine borers. Marine sediments contained large number of saprophytic fungi capable of degrading cellulose and hydrocarbons. Brackish water sediments from Sewri in Bombay and Agasaim on Zuari river in Goa harboured active hydrocarbon utilizers. Sediments from Chapora and Mandovi rivers in Goa showed a significant cellulolytic population. Mangrove vegetation in these areas also showed a similar trend and a number of ascomycetes and deuteromycetes, possibly responsible for the degradation of detrital material in the vegetation were isolated. From marine algae phycomycetes and yeasts were isolated.

In India, considerable work has been done on the fungi from marine environment[1-4]. In the present investigation fungi have been isolated from immersed timber, sediments, mangrove vegetation and algae and their role in the tropical environment has been studied to evaluate their contribution to bioproductivity.

Materials and methods

Collection of samples—Mud samples, from Sewri, Colaba and Bandra in Bombay and Chapora, Panaji and Agasaim in Goa, were collected by immersing hollow cylindrical glass column through the surface of water into sediments and scooping out the cores. Roots, stem and leaves of the *Avicennia* in the mangrove marshlands from Sewri and Bandra in Bombay and Chapora, Siolim, Old Goa and Agasaim in Goa were collected.

Algal samples were collected from Colaba Dandi in Bombay. Cellulolytic and wood inhabiting fungi were trapped and isolated using suitable modifications of the methods given earlier[5-9].

In the trapping technique employed, sterilized timber test panels (8 in. × 4 in. × $\frac{1}{2}$ in.) of Indian biang (*Tetrameles nudiflora*), sal (*Shorea robesta*), Himalayan fir (*Abies pindrow*), and pyinma (*Lagerstroemia hypoluca*) were bolted on to a mild steel frame and immersed in the breakwaters around the Naval Dockyard in Bombay. Besides, timber pieces from wooden rafters immersed in a timber pond at Sewri, and drift wood from Chapora and the Mandovi rivers were also collected.

Isolation of fungi—From timber: Suitable pieces from the immersed test panels and drift wood were cut after regular intervals from 3 to 52 weeks after immersion. Samples obtained were washed in 0.05% mercuric chloride, to eliminate bacterial contamination and inoculated into 50 ml of the medium containing (g/100 ml sea water) glucose, 1; peptone, 1; and yeast extract, 0.1; *p*H, 6. The medium was sterilized by steaming the contents for 30 min for 3 consecutive days.

To isolate fungi from timber panels Czapek-Dox medium (*p*H 6) was used. Antibiotic mixture consisting of (μg/ml) tetracycline, 20; streptomycin, 40; and penicillin, 20 was incorporated into each flask to inhibit bacterial growth. The flasks were incubated at ambient temperature for 5 days. After incubation the spores of the developing colonies were inoculated into fresh agar medium. The culture thus developed on agar plate was maintained at 0°C and subcultured every 3 months.

From sediments: To isolate fungi from sediments the methods of Waksman[10] and Warcup[11] were used and the latter method gave better results.

From marine vegetation and algae: Bits of roots, stem and leaves of *Avicennia* and the algal samples were treated with 0.05% mercuric chloride to minimise bacterial contamination and then inoculated into Czapek-Dox and algal-extract medium (*p*H 6) comprising glucose, 5 g; algal extract, 300 ml; sea water, 700 ml; and agar, 30 g. The algal extract used was prepared by extracting 200 g of washed and sundried *Ulva lactuca* in 500 ml of sea water, by steaming at 100°C for 2 hr. The extract was filtered and made up to 500 ml with sea water before use. The sea water used for growing fungi in all experiments had the salinity between 20 and $30^{o}/_{oo}$.

Fungal isolates were also maintained in sterile marine sediments by inoculating the spores into the dry and sterile sediments and preserving for 2-3 yr.

The isolates were identified according to different procedures[12-15]. Identification of some isolates were confirmed by Kew Mycological Institute, UK.

Nutritional activities of isolates—Cellulolytic activity: Fungal isolates maintained on Czapek-Dox medium were later transferred to Kodata's[16] mineral salt medium with filter paper as sole source of carbon. The culture tubes were incubated for 15 days and the filter paper degradation ability of the fungi was observed visually.

Hydrocarbon degrading ability: This was evaluated in the mineral nutrient solution containing (g/litre) NH_4NO_3, 1; KCl, 0.5; NaCl, 10; and $MgSO_4.7H_2O$, 0.5; *p*H, 5.5. After autoclaving 9.4 ml of KH_2PO_4 and 0.6 ml K_2HPO_4 (10% solutions) were added.

The medium was then dispensed (10 ml) into sterile 25 ml test tubes. The tubes were inoculated separately with different fungal isolates (3 ml of spore suspension containing 10^6-10^8 spores/ml). The medium was then overlaid with 4 ml of sterile diesel and incubated at ambient temperature for 15-20 days. The growth of the culture at the oil-water interphase indicated that the fungi were capable of degrading the mineral oil.

Results and Discussion

Immersed and drift wood samples harboured 3×10^2 to 8×10^4 organisms/g sample (Table 1) indicating that growth of these organisms could help in enhancing the biomass and bioproductivity in the marine environment. Timber panels like pyinma and Himalayan fir were more susceptible to fungal attack than Indian Biang. Meyers and Reynolds[17] observed that cell wall of wood submerged was primarily attacked by the marine fungi prior to attack by marine borers like the *Teredo* and the *Limnoria* species. The cell wall of certain timbers like Indian biang may not easily be

Table 1—Fungi from Wood Immersed in the Marine Environment

Sample	Organisms/g sample		Organisms associated
	After 20-25 weeks	After 45 weeks	
			Bombay
Timber immersed in break waters around NCML			
Sal	5×10^3	3×10^2	*Verticillium* sp.[a], *Aspergillus nidulans*[a], *Ceriosporopsis halima*[a], *Aspergillus candidus*[a,b] *Penicillium* sp., *Geotrichum* sp.[b]
Pyinma	8×10^3	6×10^2	*Phoma* sp.[a], *Chalaropsis* sp.[a], *Aspergillus terricola*, *Penicillium* sp., *Chaetomium* sp.[a] *Scopularopsis* sp.[a], *Mucor* sp., *Aspergillus niger*
Himalayan fir	3×10^4	3×10^3	*Chaetomium* sp.[a], *Aspergillus terreus*[a], *A. sydowi*, *Ceriosporopsis halima*[a], *Penicillium funiculosum*[a]
Indian biang	6×10^2	5×10^2	*Aspergillus candidus*[a], *Trichoderma koningi*[a], *Helminthosporium* sp.[a], *Aspergillus wenti*, *Phoma* sp.[a]
Wood rafters immersed in brackish water timber pond at Sewri	9×10^3	6×10^3	*Monosporium* sp., *Curvularia* sp.[a] *Aspergillus fumigatus*[a], *A. ochraceuous*[a], *Cladosporium berbarum*
			Goa
Drift wood			
Chapora river	8×10^4		*Trichoderma* sp.[a], *Chaetomium globosum*[a], *Penicillium chrysogenum*, *Aspergillus niger*, *A. flavus*, *Aspergillus* sp.[b], *Alternaria* sp., *Stemphylium* sp.
Mandovi river	5×10^3		*Penicillium funiculosum*[a], *Cunnighamella* sp. *Aspergillus flavus*, *A. fumigatus*[a], *Phoma* sp.[a], *Fusarium oxysporum*[a], *Curvularia lunata*[a,b], *Stemphylium* sp.

a = Cellulolytic activity
b = Hydrocarbon utilization

susceptible to primary fouling by fungi hence are not easily degraded as compared to susceptible timbers like Himalayan fir. The growth of fungi on susceptible timbers was faster reaching optimum around 20-25 weeks and the population considerably reduced when submerged for more than 45 weeks (3×10^3 cells/g). This can be attributed to the growth and development of marine borers after 45 weeks, which utilise fungal protein as a nitrogen source[18].

It was observed that of the 33 isolates from 4 submerged wood, 19 possessed cellulose degrading ability. These results lend support to earlier work[7,19,20].

Among the isolates, common in both studies, *Chaetomium globosum*, *Aspergillus nidulans*, *Ceriosporopsis halima* and species of *Stemphylium*, *Phoma* and *Alternaria*, were conspicuously prominent.

Coastal and estuarine sediments harboured 38% hydrocarbon utilizing and 25% cellulose degrading fungi (Table 2). Conspicuous among the hydrocarbon utilizers were *Cladosporium resinae* and *Pullularia pullulans*, isolated from mineral oil polluted areas of Sewri in Bombay. Sediments as a whole from Bombay and Goa harboured large number of saprobic fungi imperfectii, indicating their role in the degradation of organic particulate materials in the sediments. Pugh[21] reported that coastal soils harboured large number of fungi which grew luxuriantly due to the influx of terrestrial nutrients in the water. Pawar and Thirumulachar[22], isolated 37 halophilic soll fungi, from the brackish waters and the mangrove swamps of Sewri, Bandra, Colaba and Bhandup in Bombay. The sediments from the 3 major rivers in Goa show comparatively lesser number of hydrocarbon utilizers than cellulose digestors (Table 2) thus indicating that brackish waters in Bombay possibly contain considerable cellulosic material from drifting vegetation which enhances the growth of cellulose digesting flora.

The fungi were actively associated with the dead vegetation, roots and stem of *Avicennia* from various areas in Bombay and Goa (Table 3) and the total count was very high. Kohlmeyer[23] reported abundance of saprobic fungi in mangrove vegetation. The fungi play an important role in cycling the nutrients and stabilising the rich organic detrital material in the mangrove environment.

Various parts of *Avicennia* collected in Goa harboured very strong cellulolytic fungi like *Trichoderma koningi*, *Aspergillus fumigatus*, *Penicillium funiculosum* and species of *Scopularopsis* besides others. parts collected from the mangroves at Sewri also harboured potential hydrocarbon utilizers like *Botrytis* sp. and *Pullularia pullulans*, confirming the earlier indication of presence of mineral oil in the area. *Avicennia* parts from mangrove at Agasaim on Zuari river in Goa showed the presence of *Helminthosporium* and *Pullularia pullulans* associated in hydrocarbon utilisation and this may be due to the mineral oil spillage from numerous barges carrying iron ore.

Counts of fungi from algae were comparatively low (Table 4). Unlike the above ecological habitats studied marine algae found to harbour considerable number of yeasts and lower fungi. Cribb and Cribb[24] had isolated parasitic fungi on algae. The presence of lower fungi suggests parasitic association, which requires further

Table 2—Fungi from Sediments of the Marine Environment

Sample	Organisms/g sample	Organisms associated
		Bombay
Mud from brackish water		
Colaba	4×10^3	*Cladosporium resinae*[b], *Scopularopsis* sp.[a], *Pullularia pullulans*[b], *Penicillium herquei*[b], *Circinella* sp.
Sewri	9×10^4	*Spicaria di varicata*, *Curvularia* sp.[b], *Aspergillus fumigatus*[a], *Humicola* sp.[b], *Circinella* sp., *Cunninghamella* sp.
Bandra	4×10^4	*Fusarium oxysporium*[a], *Geotrichum* sp.[b]. *Mucor hiemalis*, *Chaetomium globosum*[a], *Aspergillus niger*, *Penicillium* sp.[b], *Cladosporium herbarum*[b]
		Goa
Sediments from Mandovi river at Panaji	2×10^4	*Syncephalastrum* sp.[b], *Bisporomyces* sp.[b], *Aspergillus versicolor*, *Lagendium* sp., *Rhizopus* sp.
Chapora river at Chapora	6×10^4	*Dendryphiella saline Trichoderma koningi*[a], *Curvularia* sp.[b], *Geotrichum* sp.[b], *Rhizopus* sp., *Labyrinthula* sp., *Aspergillus fumigatus*[a]
Zuari river at Agasaim	8×10^3	*Pullularia pullulans*[b], *Fusarium* sp., *Aspergillus terreus*[a], *A. flavus*, *Cladosporium herbarum*[b]

a = Cellulolytic activity
b = Hydrocarbon utilization

Table 3—Fungi Associated with the Mangroves

Avicennia part	Organisms/g sample	Organisms associated
		Bombay
At Sewri		
Stems	8×10^3	*Gonnatorrhodiella* sp., *Cladosporium herbarum*[b], *Aspergillus flaviceps*, *Penicillium* sp.
Roots	1.5×10^4	*Aspergillus candidus*[a], *Monosporium* sp., *A. flavus*, *A. nidulans*, *Phoma* sp.[a], *Botrytis* sp.[b], *Trichoderma lignorum*[a]
Dead and decaying leaves	6.3×10^4	*Fusarium* sp.[a], *Geotrichum* sp., *Aspergillus niger*, *Pullularia pullulans*[b], *Humicola* sp.[b], *Cephalosporium* sp. *Rhizopus* sp. Umbellula sp., *Circinella* sp.
At Bandra		
Stems	2.7×10^3	*Phoma* sp.[a], *Cladosporium herbarum Chaetomium globosum*[a], *Aspergillus oryzae*[b], *A. repens*
Roots	7.6×10^3	*Fusarium* sp.[a], *Geotrichum* sp., *Aspergillus* sp., *A. sydowi*, *A. carneus*, *Cephalosporium acremonium*
		Goa
At Chapora		
Stems	5.3×10^3	*Cladosporium* sp.[b], *Trichoderma koningi*[a], *Curvularia* sp., *Penicillium* sp., *Monilia* sp.
Roots	8.3×10^3	*Aspergillus fumigatus*[a], *Rhizopus* sp., *Syncephalastrum* sp., *A. sydowi*, *Alternaria* sp.
Decaying leaves	2×10^6	*Trichoderma koningi*[a], *Dendryphiella salina*, *Aspergillus fumigatus*, *Penicillium* sp., *Synchytrium* sp., *Alternaria* sp.
At Siolim on Chapora river		
Stems	3×10^3	*Aspergillus wenti*, *A. nidulans*[a], *Alternaris* sp.[b], *Penicillium chrysogenum*, *Penicillium* sp.
Roots	4.1×10^3	*Aspergillus wenti*, *A. nidulans*, *Cladosporium* sp., *Fusarium* sp.[a], *A. sydowi*, *Monilia* sp.[b]
At Old Goa on Mandovi river		
Stems	9.8×10^2	*Cunnighamella* sp., *Helminthosporium* sp.[b], *Scopularopsis* sp.[a], *Aspergillus flavus*, *A. oryzae*, *Penicillium* sp.
Roots	2.2×10^3	*Helminthosporium* sp.[b], *Geotrichum* sp., *Sporotrichum* sp., *Penicillium* sp.
Decaying roots	2×10^4	*Cunnighamella* sp., *Rhizopus* sp.[b], *Geotrichum* sp., *Cladosporium* sp., *Aspergillus flavus*, *Penicillium funiculosum*[a], *Penicillium* sp.
At Agasaim on Zuari river		
Stems	8×10^2	*Pullularia pullulans*[b], *Fusarium* sp.[a], *Penicillium* sp., *Helminthosporium* sp.[b], *Aspergillus oryzae*
Roots	3×10^3	*Fusarium* sp.[a], *Helminthosporium* sp.[b], *Aspergillus flavus*, *A. niger*, *Penicillium sydowi*, *Penicillium* sp., *Sporotrichum* sp.
Decaying leaves	7×10^4	*Pullularia pullulans*[b], *Geotrichum* sp., *Monosporium* sp., *Aspergillus terreus*[a], *A. fumigatus*[a], *Penicillium* sp., *Cunninghamella* sp.

a = Cellulolytic activity
b = Hydrocarbon utilization

Table 4—Fungi Associated with Algae in the Marine Environment

Alga	Organisms/g sample	Organisms associated
Gracilaria	6×10^2	*Cladosporium herbarum Geotrichum* sp., *Synchytrium* sp.
Caulerpa setularoides	6×10^2	*Penicillium janthinellum Acremonium* sp., *Syncephalastrum* sp., *Labyrinthula* sp., *Rhizophydium* sp.
Chaetomorpha	3×10^3	*Cylindrocephalum* sp., *Syncephalastrum* sp., *Rhizopus* sp., *Aspergillus flaviceps*, *Mucor* sp., *Rhodotorula* sp., *Saccharomyces* sp.[b]
Cladophora	6×10^2	*Fusarium* sp.[a], *Geotrichum* sp., *Monilia* sp., *Candida* sp., *Saccharomyces* sp.
Ulva lactuca	5×10^3	*Aspergillus flavus*, *A. oryzae*, *Sporotrichum* sp., *Geotrichum* sp., *Labyrinthula* sp., *Synchytrium* sp., *Rhodototula* sp. *Candida* sp., *Pullularia pullulans*[b]
Sargassum	2×10^3	*Rhizopus* sp., *Circinella* sp., *Cunninghamella* sp., *Aspergillus flaviceps*, *Pullularia pullulans*, *Candida* sp.

a = Cellulolytic activity

b = Hydrocarbon utilization

investigation. The presence of yeast species (*Candida* and *Saccharomyces*) on algae indicates that these organisms may be obtaining rich nutrient from the extracellular algal polysaccharides or from decaying algal materials. The proteolytic and the pectinolytic activities of these isolates from algal association would be of interest.

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Food & Feeding Habits of *Johnius axillaris* (Cuvier) Off Waltair Coast

K SRINIVASA RAO & K V S JANARDHANA RAO
Department of Zoology, Andhra University, Waltair 530 003

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Food and feeding habits of *J. axillaris* (9 to 20.6 cm standard length) were studied from May 1977 to April 1978 using the points, volumetric and frequency of occurrence methods. Crustaceans, mainly composed of prawns, formed the bulk of the stomach contents followed by *Squilla*, teleosts, polychaetes and crabs in the order of abundance. There was no marked seasonal variation in the average amount of feeding and feeding index. However, the feeding intensity was high during May, June, August and September. The index of preponderance was calculated to grade the food items preferred. Comparison of all the results showed that in a carnivore like *J. axillaris* the 3 methods are equally useful.

Information on food and feeding habits of fishes facilitates understanding of their feeding adaptations, growth, fecundity, migrations and other related aspects. Comprehensive accounts of food and feeding habits of marine fishes have been published by earlier workers[1-4]. The present study on seasonal variations in the food of *Johnius axillaris* is complimentary to the cursory analysis made by Suseelan and Nair[4].

Materials and Methods

Sciaenids form nearly 30% of the total catches of Visakhapatnam, occurring throughout the year. *J. axillaris* constitutes roughly 40% of the sciaenid landings during the 1st and 2nd quarters of the year with their peak abundance during February to May, declining thereafter and reaching the minimum during October to December.

Samples were collected from the trawl catches during May 1977 to April 1978, except during October to December when samples were not available. A total of 555 specimens were collected at random from different boats (twice a week) and immediately preserved in 5% formalin for subsequent analysis.

Quantitative and qualitative analyses of the stomach contents were made using points, volumetric and frequency of occurrence methods[5,6]. The degree of distension of the stomach walls[2] was taken into account for determining the amount of feeding. Points (0.1 to 1) were alloted to different food items according to their proportions in the stomach contents and later summed up and scaled down to percentages. Volume of different food items was also measured by the displacement method. Frequency of occurrence was also noted.

Average amount of feeding was calculated for each month by giving numerical values of 0, 0.25, 0.5, 0.75, 1 and 1.5 respectively for empty, $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, full and gorged stomachs. Feeding index for any month was calculated as the ratio between the number of specimens having stomachs $\frac{3}{4}$ full and above and the total number of fish examined during that month multiplied by 100 (ref. 7).

Number of empty and everted stomachs were noted in each month and the everted stomachs were excluded from the calculation of feeding index, average amount of feeding and percentage of empty stomachs, as it is not known whether the stomachs were everted due to fright or some cause other than absence of food at the time of hauling (Table 1).

Since the fish is known to be a carnivore, the 'index of preponderance'[8] was also considered.

Results

Table 1 shows the total number of stomachs examined during each month, the number of empty and everted stomachs, the average amount of feeding, feeding index and the percentage composition of the different food items in the diet of *J. axillaris* according to the different methods.

Of the 555 specimens examined 158 had empty stomachs and 33 possessed everted stomachs. The percentage of empty stomachs was high in April (59.09%) and of everted stomachs was high in January (28.57%).

There was no marked seasonal variation in the average amount of feeding. However, high values of average amount of feeding were observed reaching more than 0.8 (more than $\frac{3}{4}$ full) in May, June, and September (Table 1). The average amount of feeding was nearly $\frac{3}{4}$ full in August and less than that in July. The feeding index also followed the same trend up to July. Unlike the average amount of feeding it was relatively high in August and September and low in

Table 1—Average Amount of Feeding, Feeding Index and Details of Stomach Analysis of *J. axillaris*

[Percentage values are given in parentheses]

Stomachs and stomach contents	Months								
	May	June	July	Aug.	Sept.	Jan.	Feb.	March	April
No. of stomachs examined	48	96	85	64	32	35	54	72	69
No. of empty stomachs	12 (25)	24 (25)	15 (18.75)	14 (22.22)	4 (15.38)	10 (40)	5 (10.87)	35 (48.61)	39 (59.09)
No. of everted stomachs	—	—	5 (5.88)	1 (1.56)	6 (18.75)	10 (28.57)	8 (14.82)	—	3 (4.35)
Average amount of feeding	0.83	0.81	0.69	0.77	0.89	0.55	0.65	0.67	0.6
No. of $\frac{3}{4}$ full and full stomachs	15 (31.25)	33 (34.38)	27 (33.75)	31 (49.21)	5 (19.23)	3 (12)	14 (30.43)	34 (47.22)	9 (13.64)
No. of gorged stomachs	11 (22.91)	19 (19.79)	6 (7.5)	6 (9.52)	7 (26.92)	—	4 (8.7)	—	4 (6.06)
Feeding index	54.17	54.17	41.25	58.73	46.15	12	39.13	47.22	19.7
Food items (Percentage composition)									
Prawns									
P	19.44	57.68	33.48	60.2	31.14	19.99	28.04	49.99	30.56
V	19.31	58.38	33.83	64.05	16.36	20	24.7	62.07	50.43
F	29.17	58.33	32.5	50.79	38.46	12	34.78	26.39	13.64
Squilla									
P	6.67	8.03	5.38	7.35	32.72	13.33	5.37	2.7	2.78
V	5.22	12.12	0.65	7.02	59.64	10	6.91	8.62	10.26
F	10.42	14.58	6.25	9.52	34.62	8	10.87	1.39	1.52
Crabs									
P	0.97	0.69	5.38	4.08	—	—	3.66	—	—
V	0.88	0.3	6.39	1.66	—	—	5.76	—	—
F	4.17	1.04	5	3.17	—	—	4.35	—	—
Polychaetes									
P	1.39	1.39	5.38	1.02	—	13.33	0.61	1.35	—
V	3.14	0.6	4.14	0.41	—	20	0.41	1.72	—
F	2.08	2.08	6.25	1.59	—	8	2.17	1.39	—
Teleosts									
P	6.39	7.9	7.69	5.92	—	—	12.2	—	—
V	22.64	19.76	13.16	16.94	—	—	25.1	—	—
F	6.25	9.38	8.75	6.35	—	—	13.04	—	—
Crustacean remains									
P	15.28	2.78	5.76	—	4.55	6.67	4.88	29.73	37.03
V	8.43	1.2	5.26	—	3.63	10	1.65	19.83	21.37
F	18.75	4.16	6.25	—	3.85	4	4.35	18.06	15.15
Teleost remains									
P	—	—	7.69	—	5.45	—	15.98	—	—
V	—	—	9.02	—	6.73	—	15.72	—	—
F	—	—	7.5	—	7.69	—	17.39	—	—
Miscellaneous									
P	50.83	21.53	29.23	21.42	25.68	46.67	29.26	16.21	25.93
V	40.38	7.64	19.55	9.92	13.82	40	19.75	7.76	11.11
F	58.33	20.83	26.25	17.46	26.92	28	28.26	8.33	9.09
Gastropod									
P	—	—	—	—	0.46	—	—	—	—
V	—	—	—	—	0.72	—	—	—	—
F	—	—	—	—	3.85	—	—	—	—
Albunea									
P	—	—	—	—	—	—	—	—	3.7
V	—	—	—	—	—	—	—	—	6.83
F	—	—	—	—	—	—	—	—	1.52

P = Points; V = volume; and F = frequency

January. The discrepancy between the average amount of feeding and feeding index in August and September was due to the preponderance of $\frac{3}{4}$ full and full stomachs in August (49.21%) giving rise to a high index and $\frac{1}{2}$ full stomachs (53.85%) with some full (gorged) stomachs (26.92%) in September (Fig. 1).

The amount of feeding and feeding index were rather low from January to April, which is after the period of slack season (October to December) of the fishery, as observed in the present study.

Prawns constituted the most important food item in the diet of *J. axillaris*, reaching a peak in August (60.2%). Except in May, abundance of the food items in the stomach contents was seen seasonally in March, April (1978) and June-August (1977). There was a decline from September onwards. Their frequency of occurrence was, however, high during June and August only. Despite high percentage composition of the items by points as well as volumetric methods in March, their frequency was rather low. It shows that the prawns eaten as food in March were of bigger size. Their identity was however not clear.

Percentage composition and frequency of occurrence of *Squilla* were relatively high during September (32.72%) to the extent of compensating the fall in the prawn content from August to September. The values were more or less uniform in the remaining months except March and April when they were very low.

Crabs were present in the diet during only certain months. Their frequency of occurrence was more or less the same in all months of their occurrence except June. But they constituted a considerable proportion of the food in July and August (5.38 and 4.08% respectively).

Highest abundance of polychaetes (13.33%) was observed in January and they were also of considerable importance in July. Teleosts have occurred with more or less the same frequency throughout except some months when they were not present in the diet. Gastropods and *Albunea* appeared in the stomach contents occasionally, the former more frequently in September and the latter in April.

Values of index of preponderance showed (Table 2) that prawns, *Squilla*, and teleosts occupied the 1st, 3rd and 4th places in the diet of *J. axillaris*, with miscellaneous matter occupying the 2nd place (Table 2).

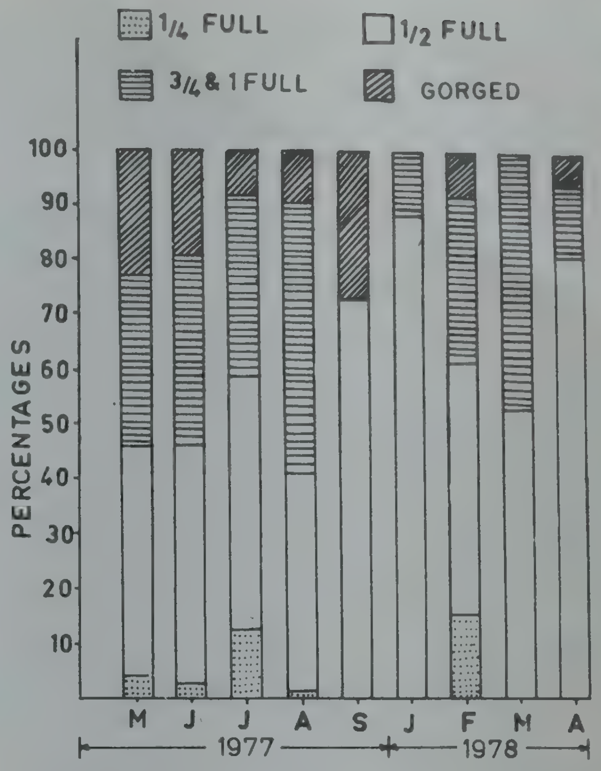

Fig. 1—Frequency of occurrence of different degrees of distension of the stomachs in different months

The values of the summed up and scaled down percentages by the points and volumetric methods agree well in the case of prawns, *Squilla*, crabs and teleost remains. In the case of teleosts and crustacean remains which constitute a smaller bulk of the stomach contents than prawns and *Squilla*, the volumetric percentage is more in the former and less in the latter when compared to the points method. This is due to relatively greater compactness of teleosts rendering the eye estimation to be rather low in alloting points while the measurement of volume by the displacement method is certainly accurate. On the other hand crustacean remains, because of looseness of dismembered appendages and musculature have gained rather spuriously more points by eye estimation. This is an inherent draw back in the points method.

Hynes[5] has stated that for any fish with a generalised diet, provided a large number of specimens are observed, any of the commonly accepted methods of assessing the composition of the diet of the fish from the gut contents will give substantially the same results. He has further stated that those food items important in the diet will always stand out clearly from those that are occasional or rare or so unimportant. In the present study prawns stand out clearly as the most important food item by all the 3 methods (Table 2). The index of preponderance also shows that the importance of the different food items follows the same order as seen by the other 3 methods.

Discussion

J. axillaris mostly occurs in the inshore waters feeding on the food material available on the shelf region. Keast and Webb[9], Chao and Musick[10] have correlated the differences in the body shapes, mouth position and structure to the type of food that the fish feeds. *J. axillaris* which is a small sciaenid having a robust compressed body, with a terminally placed oblique mouth with upper and lower jaws subequal

Table 2—Percentage Composition of Different Food Items by Different Methods and the Index of Preponderance of *J. axillaris*

[Figures given in parentheses indicate the order of importance of the food items]

Food items	Percentages			V_iO_i	Index of preponderance
	Points method	Occurrence method (O_i)	Volumetric method (V_i)		$\frac{V_iO_i}{\Sigma V_iO_i} \times 100$
Prawns	40.57	39.62	43.07	1706.43	70.43 (1)
Squilla	7.8	10.28	11.6	119.25	4.92 (3)
Crabs	2.15	2.36	1.87	4.41	0.18 (8)
Polychaetes	2.4	2.78	1.74	4.84	0.2 (7)
Teleosts	5.73	6.21	16.07	99.8	4.12 (4)
Crustacean remains	9.85	9.42	5.13	48.33	2 (5)
Teleost remains	3.5	2.43	3.28	11.25	0.46 (6)
Gastropod	0.03	0.21	0.04	0.01	0 (10)
Albunea	0.27	0.21	0.38	0.08	0.01* (9)
Miscellaneous	27.7	25.48	16.82	428.57	17.68 (2)
	100	100	100	2422.97	100

O_i=Occurrence index; V_i=volumetric index

*This is a nominal value for the purpose of grading while the actual value is much less (0.003)

bearing small and widely spaced teeth is morphologically adapted to feed on small organisms only in the mid waters and near the bottom.

Following Longhurst[11], *J. axillaris* may be categorised as fish feeding on active members of the bottom and is also ichthyophagous to some extent.

Druzhinin[12] has remarked that the sciaenids generally feed on big sized crustaceans mainly composed of shrimps, and fish also. Since all the important food organisms consumed by *J. axillaris* are active swimmers it may be called a predator.

Suseelan and Nair[4] suggest that teleosts rank first in importance in the food of *J. axillaris*, supplemented by prawns off Bombay. But in the present study it is noticed that prawns formed the most important food item and that teleosts are in 4th place. Amphipods, cephalopods and salps are observed in the stomachs of these fish off Bombay. These items are not at all observed in the present study although amphipods and cephalopods are observed by Rao[2] in the stomachs of some of the demersal fishes off Waltair.

High frequency of empty stomachs in March and April coincides with an all crustacean diet. The fishes are mostly in the maturing condition (stages 3 and 4) and hence not likely to abstain from feeding, but may be appetitive in behaviour. The patchy distribution of crustaceans on the fishing grounds during the season is perhaps responsible for this feature rendering the fish without their favourite food for a few hours resulting in larger number of empty stomachs. In the other seasons small teleosts which are of uniform distribution, form part of the food and are often observed in various degrees of digestion in the stomachs without rendering them completely empty.

The fall of the prawn content in the stomachs in September coincides with the decline in *J. axillaris* fishery and the increased occurrence of prawns in the stomachs in January again coincides with the rise in the fishery from February onwards. It shows that the availability or otherwise of some prawns of ingestible size influences the fishery. From this standpoint it is necessary to establish the identity of the species of prawns eaten by the fish, in future studies.

Acknowledgement

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Short Communications

Distribution of Organic Matter in Shelf Sediments Off Kakinada, East Coast of India

M KALESHA

Department of Geology, Andhra University, Waltair 530 003

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Organic matter of surface sediments and bottom sediments of cores from the Kakinada bay and the shelf of Kakinada-Pentakota coast has been estimated. Organic matter increases seaward from shore in both the surface and bottom sediments of the cores as the φ mean size increases. It tends to decline with depth in all core samples except in a few from the southern part of the bay. Planktons and land derived plant material are considered to be the source of organic matter. Sediment texture and its differential rates of deposition seem to control the organic matter content in the sediments.

Reports of organic matter content of sediments of the shelf regions from the tropical belt are not many[1]. The organic matter content of the marshes and the lower reaches of the channels of Godavari[2], Krishna[3] and Mahanadi[4] on the east coast of India have been published. Present paper reports the organic matter content of the sediments of the Kakinada bay and the innershelf between lat. 16°45′ and 17°20′N, long. 82°15′ and 83°0′E, which has not been investigated earlier in detail.

Sediment samples were collected down to a depth of about 45 fm from the shelf between Hope Island and Pentakota and from the Kakinada bay during January 1976 using a mechanised boat. La Fond-Dietz snapper and short gravity corer were used for sample collection. The snapper samples represent essentially the top few inches of the sediment while the cores range 20 to 24 in. in length.

About 175 surface sediment samples and 40 core samples at 20 in. depth were selected for organic matter estimation. They were dried at 50°C and then pulverished. From the sample powder exactly 0.5 g was taken for the organic matter estimation[5]. The amount of organic matter was obtained by multiplying the organic carbon values by the recommended factor (1.34) of Jackson[5].

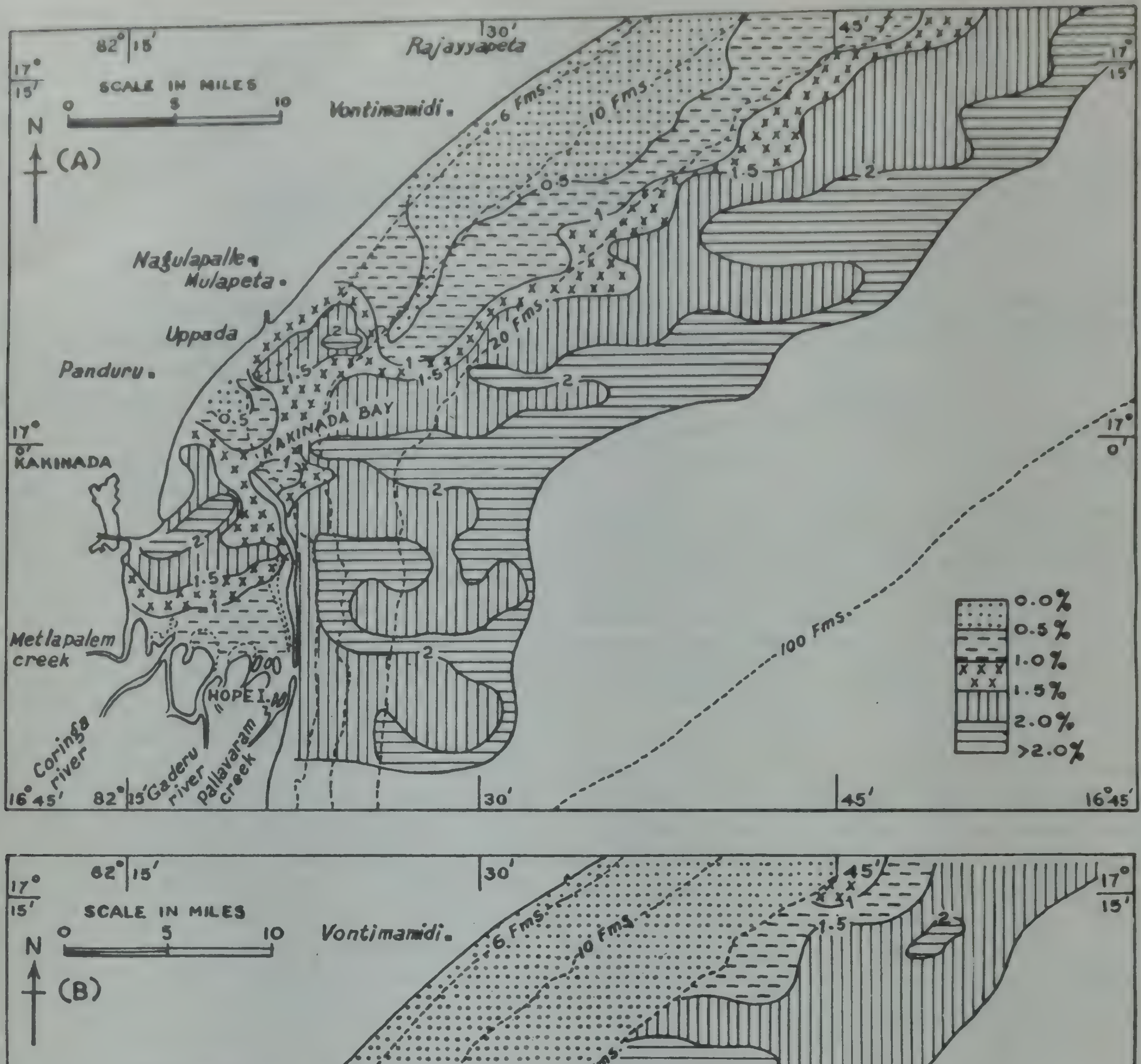
Nature of sediments—The bay sediments consist of clayey silts and silty clays except along the southern and eastern margins where clayey silty sands occur according to the nomenclature of Folk modified by Lewis[6]. The clayey silts and silty clays extend into the northern part of the shelf area up to Mulapeta. The near shore area of the shelf is covered by sand fraction all along the coast and it is successively followed by sand-silt-clay, clayey silts and silty clays respectively towards off shore.

Nearshore fine-fractions of the surface sediments are brown while the deeper fine-fractions are gray.

Areal variation of organic matter in the surface sediments and at a depth of 20 in. from the surface are shown in Fig. 1. Organic matter content of surface sediments of the area varies from 0.39 to 2.81% (av. 1.8). Surface sediments of the bay consist of >1% organic matter having the maximum amount of 2.4% at the centre. The southern and eastern parts of the bay consist of relatively low per cent of organic matter in comparison to western and northern parts. The organic matter in the northern part of the shelf area ranges from 0.53 to 2.81% seaward whereas east of sand spit it varies from 1.77 to 2.29%.

Organic matter in the core sediments at 20 in. depth varies from 0.3 to 2.2% seaward (av. 1.25). In the southern part of the bay the bottom sediments of the cores are relatively high in organic matter and it gradually decreases towards the head of the bay across the centre.

Sverdrup[7] has pointed out that abundant supply of organic matter in the overlying column of water, rapid rate of accumulation of fine grained inorganic matter and a low oxygen content of water immediately above the floor sediments will favour preservation of organic matter in sediments. It has been observed that fine grained sediments are richer in organic matter than coarse grained[1,8-12]. Higher organic matter content of sediments beyond 20 fm in the area of study may be attributed to relatively high plankton production rates associated with upwelling of waters[13,14] and high sediment supplies from the Godavari River, which have been shown to be transported to north and northeast from its mouths[15]. In depths <20 fm currents are very strong as is reflected by the coarse sands carpeting in this part of the shelf. Conditions obviously are unfavourable for accumulation of organic matter and hence the low values. In the Kakinada bay higher organic matter content is associated with silty clays that are prominent in the northwestern and central parts of the bay. The coarse


(A)
(B)
N
SCALE IN MILES
0
5
10
17° 15'
17° 0'
16° 45'
82° 15'
30'
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Rajayyapeta
Vontimamidi
Nagulapalle
Mulapeta
Uppada
Panduru
KAKINADA
KAKINADA BAY
Metlapalem creek
Coringa river
Gaderu river
Pallavaram creek
HOPE I.
6 Fms.
10 Fms.
20 Fms.
100 Fms.
0.5
1
1.5
2
0.0%
0.5%
1.0%
1.5%
2.0%
>2.0%
Uncovered area

Fig. 1—Distribution pattern of organic matter in (A) surface sediments and (B) core sediments (at 20 in. depth from surface) off Kakinada shelf

grained sediments of the eastern and southeastern parts of the bay are relatively poor in organic matter content. Assuming that organic matter supply is uniform in the bay the grain size appears to control the organic matter content of the sediments.

The average organic matter content for the surface sediments of the bay and the shelf is higher than that of the Godavari[2], the Krishna[3] and the Mahanadi[4] deltas. This may be due to a greater plankton contribution to the sediments of the shelf and higher sediment accumulation rates in the open sea environment.

In most of the core samples, the organic matter decreases with depth from the surface except in a few cores in the southern part of the bay where the organic matter increases with depth. Decrease of organic matter with depth in the core samples can be explained by compaction, degradation, decomposition, loss of moisture and synthesis to other compounds during its diagenisis. This corroborates the earlier view of Setty and Madhusudana Rao[16]. The increase of organic matter with depth in the core samples of the southern bay may be due to relatively higher rate of organic matter accumulation at the time. The rapid growth of sand spit and consistant northward extension of tidal flats in the southern part of the bay provide evidence of rapid sedimentation during Recent. The small patch showing anomalous concentration of organic matter in the bottom sediments of the cores of the shelf area may be due to the differential rate of plankton production and deposition. The organic matter in the bay and shelf may be ascribed to the following sources: (1) The land derived plant material mainly from the adjacent mangrove swamps might have been transported to the off shore area by NE currents during the SW monsoon period as evidenced by presence of wood material in the shelf. (2) Good plankton production because of the upwelling water in the shelf. (3) The stagnation of water in the bay evidenced by reducing environment in the presence of sulphide minerals and iron ores[12].

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Photosynthetic Pigments in Coastal Ecosystems*

A PANNEERSELVAM, L KANNAN & K KRISHNAMURTHY
Centre of Advanced Study in Marine Biology, Annamalai University, Parangipettai 608 502

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Photosynthetic pigments were estimated from neritic, estuarine and mangrove biotopes of Porto Novo. The mangrove biotope gave higher values for bacteriochlorophyll *a*, bacteriochlorophyll *c* (chlorobium chlorophyll 660) and bacteriochlorophyll *d* (chlorobium chlorophyll 650) than the neritic and the estuarine biotopes. Chlorophyll *a* was higher in the estuary than in the other 2 biotopes. Dissolved oxygen, salinity, light penetration and *p*H were lower in the mangrove biotope and higher in the other 2 biotopes. Mangrove biotope seems to provide a more congenial environment for photosynthetic bacteria with higher turbidity of water, greater concentrations of organic detritus and hydrogen sulphide.

In continuation of earlier studies[1] on phytoplanktonic primary production at Porto Novo, investigations on bacterial photosynthetic production have been initiated. In the present work, chlorophyll *a*, bacteriochlorophyll *a*, bacteriochlorophyll *c* (chlorobium chlorophyll 660) and bacteriochlorophyll *d* (chlorobium chlorophyll 650) in all the 3 aquatic biotopes (neritic, estuarine and mangrove biotopes) in and around Porto Novo have been estimated.

Samples were collected biweekly from different stations[2-4] situated in the 3 biotopes. Standard methods were used for the estimation of hydrographical parameters. Estimation of chlorophyll *a* was based on the method described by Strickland and Parsons[5]. Bacteriochlorophyll fractions were estimated as described by Takahashi and Ichimura[6,7].

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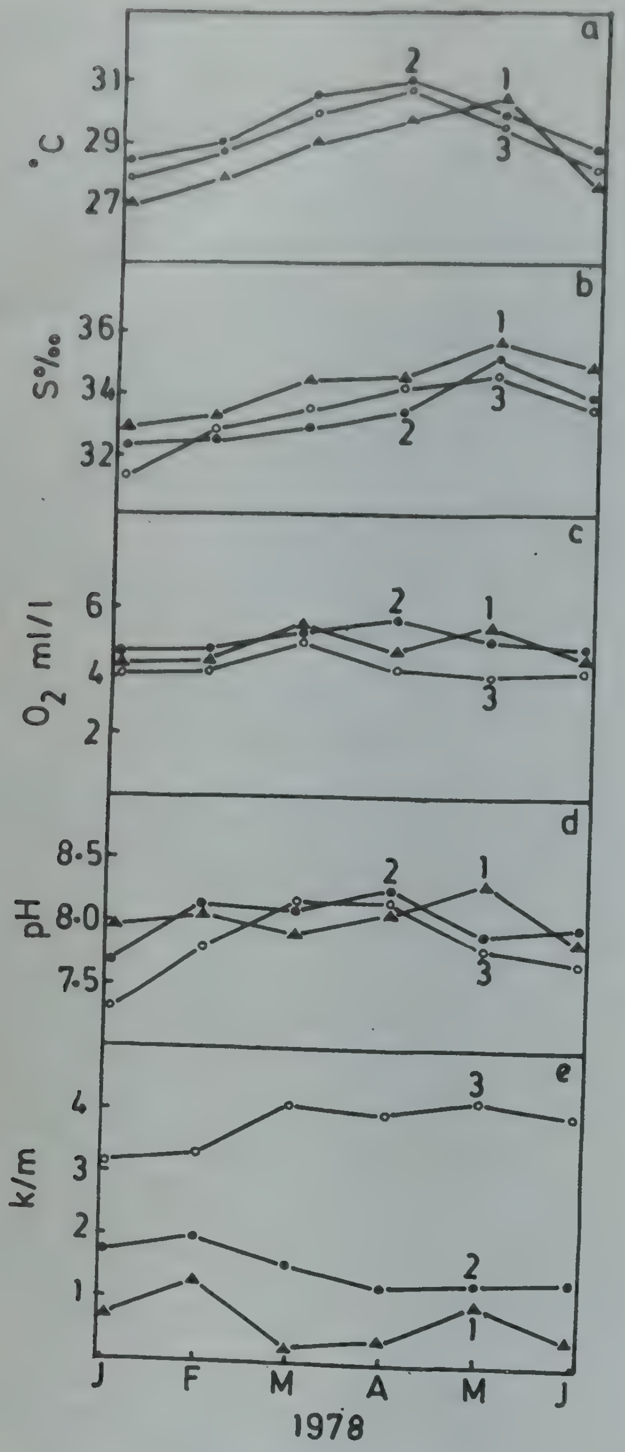

Fig. 1—Monthly mean temperature (a), salinity (b), dissolved oxygen (c), *p*H (d), and light extinction coefficient (e) in neritic (1), estuarine (2), and mangrove (3) biotopes

Hydrographical data are given in Fig. 1. Temperature did not show much variation. In general, higher values of temperature were noticed in April (summer season) and lower values during January. Salinity values were high in the neritic biotope, maximum being in May. A similar trend was noticed in the distribution of salinity in the estuarine and mangrove biotopes. Dissolved oxygen values were more or less similar in all the biotopes. The highest value was noticed during May in the neritic biotope and during April in the estuarine biotope. The mangrove biotope had low levels of dissolved oxygen. The higher values in the neritic and estuarine biotopes could be due to the liberation of oxygen by photosynthesis by the numerically abundant phytoplankton. Pierson and Castenholz[8] showed in the culture of phototrophic filamentous bacteria *Chloroflexus aurantiacus* that bacteriochlorophyll synthesis is supressed in fully aerobic conditions. This is in conformity with the present observations of higher content of bacteriochlorophylls encountered in the highly biodeteriorative and not-so-fully aerobic environmental conditions of the mangrove biotope.

There was no much variation in *p*H in all the 3 biotopes. *p*H of the neritic biotope ranged from 8 (January) to 8.3 (May), whereas in the estuarine biotope it ranged from 7.7 (January) to 8.2 (April). In the mangrove biotope, *p*H ranged between 7.9 (March) and 8.3 (May). Such a favourable alkaline *p*H along with other factors would support a higher photosynthetic bacterial biomass in the mangrove biotope. Pierson and Castenholz[9] also reported abundant occurrence of bacteriochlorophyll-like pigments in 2 types of filamentous gliding prokaryotes from alkaline hot springs of Iceland.

Light extinction co-efficient (k/m) values were more (3.2 to 4.2) in the mangrove biotope owing to suspended materials in the water, muddy bottom and flow of freshwater from the adjacent channels. Similar values were recorded in this biotope earlier[1,2]. Such a low light penetration is considered to be very congenial for the growth of photosynthetic bacteria. Pfenning and Cohen-Bazire[10] reported that low light intensity is required for the successful growth of 2 strains of *Pelodictyon clathriforme* in culture. Pierson and Casternholz[8] also observed that specific contents of bacteriochlorophylls *a* and *c* decreased with increasing light intensity.

Throughout the study period lower values of physiologically active phytoplanktonic chlorophyll *a* were recorded from the mangrove biotope than from the other 2 biotopes. Estuarine biotope showed the highest values for chlorophyll *a*, maximum (52.1 mg/m^3) being during May. Bacteriochlorophyll *a* showed high values in the mangrove biotope. In the neritic biotope it showed a low value in February and a high value in May. Maximum values for bacteriochlorophyll *c* were noticed during May in all the biotopes. Values for bacteriochlorophyll *d* showed wide variation (Fig. 2). The higher values for different bacteriochlorophyll fractions in the mangrove biotope indicate a very active and rich microbial photosynthetic activity and production. Higher values of primary production (7.86 gC/m^3/day) were reported from the mangrove biotope[3,4,11]. Kannan and Krishnamurthy[1] suggested that apart from nannophytoplankton, the photosynthetic bacterioplankton could also contribute for higher values of primary production in the mangrove biotope.

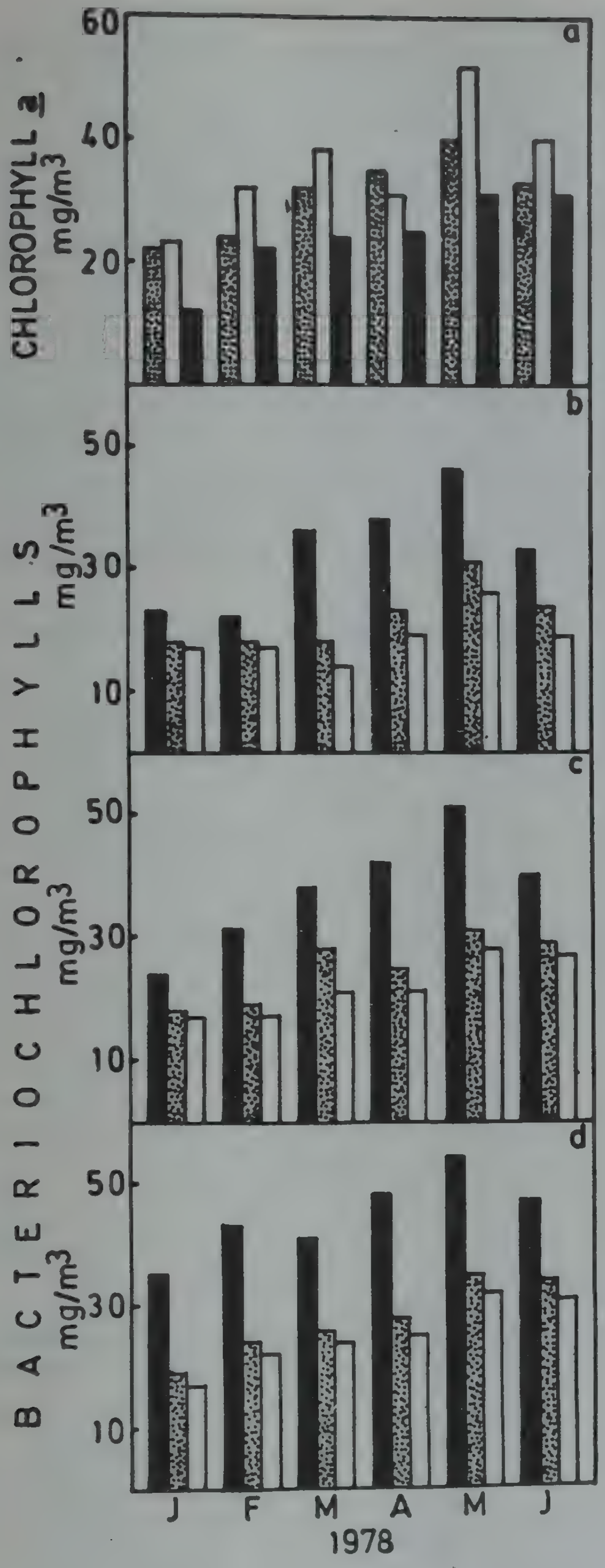

Fig. 2—Monthly mean of chlorophyll *a* (a) in different biotopes and bacteriochlorophylls in neritic (b), estuarine (c) and mangrove (d) biotopes [Different biotopes in (a) : Stippled, neritic; open, estuary; and shaded mangrove. Different bacteriochlorophylls in (b to d) : shaded, *a*; stippled, *c;* and open, *d*]

The mangrove biotope has the potential to generate good amount of hydrogen sulphide from organic matter derived from the submerged mangrove flora and fauna. The presence of hydrogen sulphide in this biotope would perhaps be suitable for the luxuriant growth of photosynthetic bacteria. The sulphate content in the mangrove biotope is often as high as 516 ppm/litre and this would account for the availability of more hydrogen sulphide. Czeczua[12] concludes that besides enriching water with dissolved organic matter the bacteria also absorb hydrogen sulphide, thus evoking a self-clarifying response of water; this stresses the importance of hydrogen sulphide as the electron donor for bacterial photosynthesis. Studies[13] on the aquatic environment of Goa have also revealed that the photosynthetic bacteria grow better in an environment containing hydrogen sulphide and carbondioxide or any organic carbon compound. The present study shows that the mangroves presenting favourable conditions such as higher light extinction, alkaline *p*H, optimum dissolved oxygen, organic matter and hydrogen sulphide may sustain good bacterial photosynthesis.

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Cellulolytic Activity of Streptomycetes Isolated from the Digestive Tract of a Marine Borer

T BALASUBRAMANIAN,
P LAKSHMANAPERUMALSAMY, D CHANDRAMOHAN &
R NATARAJAN

Centre of Advanced Study in Marine Biology, Annamalai University, Parangipettai 608502

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Three cellulolytic streptomycetes were isolated from the alimentary tract of *Barnea birmanica* Philippi (Pholadidae:Bivalvia: Mollusca), collected from mangroves at Porto Novo, and their morphological, cultural and physiological properties studied. Effects of *p*H and sodium chloride on the activity of cellulases produced by the 3 isolates suggested the presence of isozymes.

Cellulose decomposing bacteria and fungi, widely distributed in the marine environment, play an important role as mineralizers of organic matter influencing the productivity of the sea[1-3]. They are also known to be involved in the deterioration of various cellulosic materials in the sea[4,5]. Information on marine cellulolytic actinomycetes is limited[6-10] and streptomycetes isolated from decaying fish nets and cordage[4] and from marine sediments[10,11] have been shown to be cellulolytic. In this communication properties of isolates of *Streptomyces* spp from the digestive tract of a marine borer (bivalve) are reported.

Three strains of *Streptomyces* spp isolated from the digestive tract of *Barnea birmanica* Philippi were used. The bivalves were collected from dead *Rhizophora* sp. in the mangrove regions near Porto Novo (lat. 11°31′ N; long. 79°50′ E). The isolates were maintained on yeast-extract glucose agar.

Sodium chloride tolerance of the isolates was tested by growing them in basal medium[5] supplemented with different concentrations of sodium chloride. The spore free solution was used for enzyme studies[11] and the reducing sugar released was estimated by Nelson's method[12].

To study the effect of *p*H on cellulose activity, the medium was prepared with 50% sea water supplemented with 1% carboxymethyl cellulose (CMC). Cellulolytic activity was measured at different *p*H levels employing acetate, phosphate and glycine-NaOH buffers.

To ascertain the effect of dialysis, the enzyme was dialysed against 2 litres of distilled water for 24 hr at 4°C, before the activity was measured.

Thirty days old dialysed culture filtrate was used as the enzyme source to study the effects of different sodium chloride concentrations on cellulase activity. Sodium chloride was added to the reaction mixtures in 1, 3, 6, 10 and 15% conc. before the activity was measured.

All the 3 isolates showed good growth in 3 and 1.5% sodium chloride but not in 0, 0.5 and 4.5%. Isolates S289 and S291 tolerated slightly higher concentration (6%). None of the isolates grew at 10% sodium chloride.

Results of the effects of different concentrations of sea water and 2 different substrates on growth and cellulase production showed increased growth rates with increasing salinity both in cellulose and CMC supplemented media but the growth rate was higher in the latter. When the incubation period was more, the growth increased at a slower rate, especially after 15 days. In general, undiluted sea water supported maximum growth of all the 3 isolates.

Cellulolytic activity was recorded in all the 3 isolates in both cellulose and CMC supplemented media, increased activity being only in media supplemented with CMC. Cellulase produced in both the media was capable of hydrolyzing both CMC and cellulose and the enzyme obtained from CMC medium always showed higher activity. Greater cellulolytic activity was not recorded corresponding with increased growth in higher salinities. In general, higher activity was recorded only in salinity range between 3.26 and 16.3‰.

The cellulase of all the 3 isolates exhibited a common peak at *p*H 5.2 (Fig. 1). The cellulase of isolate S289 showed 2 more peaks while the cellulase of other 2 isolates showed one more peak (Fig. 1). Below *p*H 3.7 and above 10.6 the activity was considerably lowered. Cellulase of the 3 isolates was not inhibited by various buffers used.

Dialysis of the enzyme resulted in reduction of the activity (Fig. 2) but when cellulose was used as substrate, a considerable increase in the activity could be seen. This was especially true for the enzyme

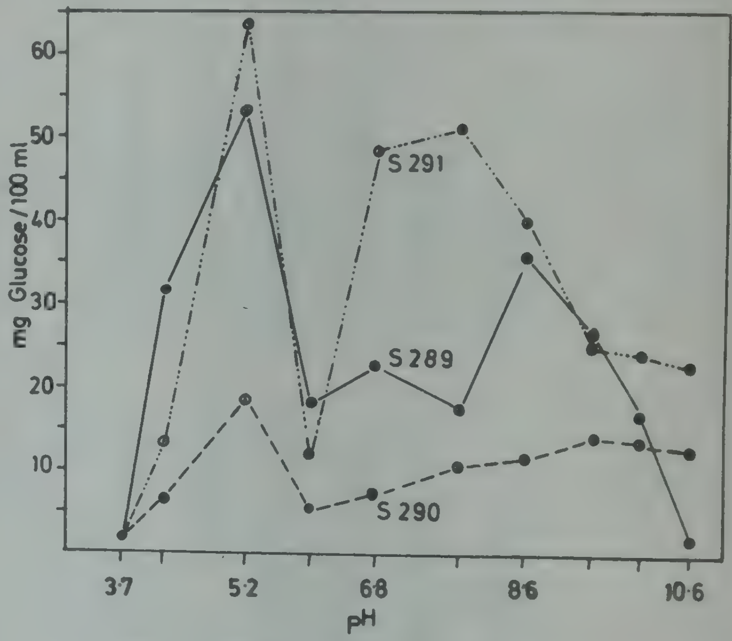

Fig. 1—Effect of *p*H on cellulase activity

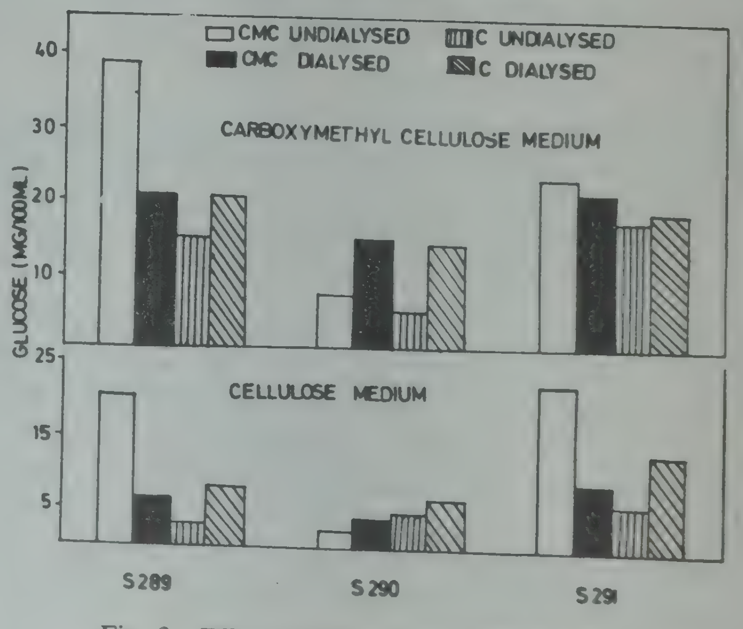

Fig. 2—Effect of dialysis on cellulase activity

obtained from cellulose medium. Dialysis of the enzyme of isolate S290 enhanced the activity when CMC and cellulose were used as substrates for assay. Evidently dialysis seems to exert an influence on the activity of cellulase in the present study.

In all the cultures, maximum activity was recorded around 3% sodium chloride concentration (Fig. 3). Reaction mixture without sodium chloride showed lowest activity. In general, the cellulase required 1-6% sodium chloride for exhibiting maximum activity. Even at 10 and 15% sodium chloride conc. activity could be recorded in both S289 and S291, but at these concentrations, the enzyme activity of S290 was less. No generalization could be made on the rate of activity in response to various concentrations of sodium chloride.

It is known that a variety of bacteria, fungi, actinomycetes and protozoa have cellulolytic properties but studies on marine cellulolytic streptomycetes are limited[4-11]. Cellulose decomposing microorganisms, often symbiotic with shipworms and other borers, appear to play a role in destruction of timbers, wooden pilings and other cellulosic structures exposed to the sea[1] as already reported in *Teredo* sp[13-16]. Eventhough the presence of a well established cellulase has not been reported so far in any marine borer, the possibility of cellulolytic bacteria or actinomycetes playing an important part cannot be ruled out.

The present isolates were capable of attacking both cellulose and CMC. With increasing salinity in the medium, their growth rate increased. For normal growth they need salinity of 15-30‰ indicating them as facultative halophiles. CMC was preferentially attacked and higher growth rates were recorded in media supplemented with CMC. Siu and Reese[17] also reported that some bacteria which did not grow on native cellulose showed growth on new water soluble derivatives of cellulose.

Cellulase of *Streptomyces* spp showed 2 *p*H optima in the present study indicating the presence of isozyme. A similar multiple cellulase system in *S. antibioticus* was found to consist of 5 components, all endocellulases[18].

Optimum *p*H for the activity of fungus derived cellulases was 5 and for bacterial cellulases 7 (ref. 1 and 2). The present study showed optimum *p*H of 5.2 which is also similar to *p*H of the gastric fluid[19,20]. Based on the *p*H activity curve it may be assumed that the cellulase of isolate S289 consists of 3 components and that of isolates S290 and S291, 2 components each.

When cellulases of S289 and S291 obtained either from CMC media or cellulose media were dialysed against distilled water and assayed with CMC, a drastic reduction in the activity was noticed. When the dialysed enzyme was assayed with native cellulose, significant increase in the activity was observed. This suggests that certain co-factors, necessary for Cx groups of enzymes, were lost during dialysis resulting in lower activity. Certain inhibitors could also have been removed during dialysis resulting in increased activity but no attempt was made to identify either the co-factors or the inhibitors presently.

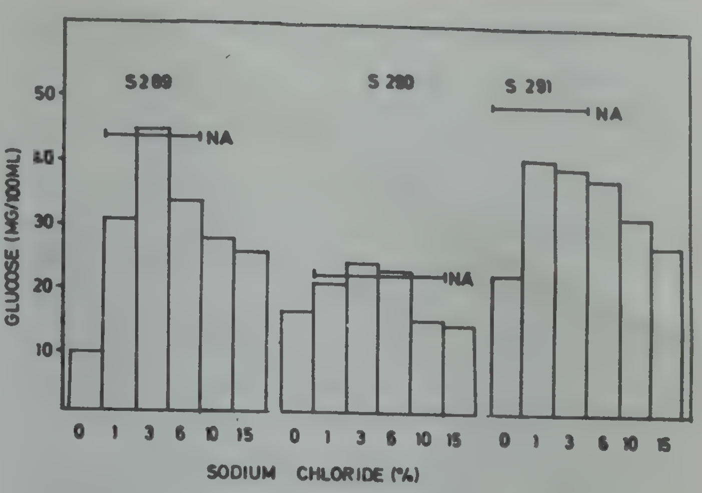

Fig. 3—Effect of sodium chloride on cellulase activity

In the present study, it was found that the cellulases from the streptomycete isolates required 1-3% sodium chloride for maximum activity and even when the concentration was increased to 10-15% there was no considerable loss in activity. In the absence of salts, poor growth and low cellulase activity was found. Rubentschik[21] also found that in *Actinomycetes melanogenes* and in in anaerobic cellulose digestors[22], decomposition of cellulose was unimpared by salt concentration up to 15% sodium chloride. The cellulases of marine origin thus seem to differ atleast in their requirements of sodium chloride and in their ability to tolerate high salinity.

Financial support received from CSIR, New Delhi is gratefully acknowledged. Thanks are due to Dr. Kenneth J. Boss, Museum of Comparative Zoology, harvad University, Cambridge, Massachusetts for his help in the identification of the borer.

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Efficiency of Energy Utilization in the Shrimp, *Metapenaeus monoceros* Fed Mangrove Leaves

V RAMADHAS & SUMITRA-VIJAYARAGHAVAN
National Institute of Oceanography, Dona Paula, Goa 403 004

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Energy budget of *M. monoceros* was estimated using 3 species (*Rhizophora mucronata, Avicennia officinalis* and *Acanthus ilicifolius*) of mangrove leaves in combination with rice bran as food. The results indicated high assimilation efficiency (86%) and low conversion efficiencies (K_1-6.45 and K_2-7.49) and the latter was attributed to the source of protein in the food.

Earlier works on food conversion efficiency in the shrimp, *Metapenaeus monoceros,* have been carried out using natural, processed and compounded feeds[1]. Mangroves are well known to support a variety of detrivorous organisms, and the nutritive value of mangrove vegetation and the biochemical composition of different stages of mangrove leaves are reported[2,3]. However, no attempt has so far been made to use mangrove vegetation as chief ingredient in compounded feeds. Hence, the present work is aimed at studying food conversion efficiency in *M. monoceros* using test diets with withering mangrove leaves.

Shrimps of 28-35 mm carapace length were collected from the mangrove bordered backwaters of Mandovi estuary. They were sorted into 3 experimental groups (10 animals each) and kept in glass tanks (40 × 20 × 20 cm) containing 10 l of seawater (sal. $15^{o}/_{oo}$; temp., 28 ± 1°C). The shrimps were acclimatized with the following test diets (%) which were offered in dry pelleted condition and fed *ad libitum*. Group I—*Rhizophora mucronata* (60) + rice bran (40), group II—*Avicennia officinalis* (60) + rice bran (40), and group III—*Acanthus ilicifolius* (60) + rice bran (40).

Biochemical composition of the test diets is given in Table 1. Other experimental procedures and calculations of energy balance were same as reported[4]. The energy estimations of the feed, test animals and faecal matter were carried with Parr (1200) adiabatic microbomb calorimeter. The experimental duration was 30 days.

Table 2 summarises the results of feeding experiments. In all groups of shrimps, the conversion efficiencies (K_1 and K_2), relative growth rate and assimilation efficiency did not vary much. The energy loss through defaecation was little (15%) when compared to the consumed food. In general, lower conversion efficiencies with higher assimilation (86%) was observed in all groups. Similar results were reported for the same species of shrimp[1,5] with reference to Tamil Nadu Agricultural University diet, white fish meal and Cooper Beta diets having about 40 to 60% protein.

Table 1—Biochemical Composition (%) of Test Diets

	Rhizophora mucronata	*Avicennia officinalis*	*Acanthus ilicifolius*
Carbohydrate	42.86	48.7	31.8
Protein	18.13	9.74	8.6
Lipid	10.25	11.65	14.95
Caloric value (cal/g dry wt)	3945	3934	3050

Table 2—Energy Balance of *M. monoceros* Fed Mangrove Leaves

[Energy values are expressed as cal/animal]

	Group I	Group II	Group III
Initial dry wt (g; W_1)	0.091	0.089	0.085
Final dry wt (g; W_2)	0.124	0.114	0.117
Weighted mean (g; $\bar{W}$)	0.108	0.102	0.101
Initial calories (I_1)	465	468	441
Final calories (I_2)	654	613	614
Production ($P = I_2 - I_1$)	189	145	173
Consumption (C)	3212	2507	2251
Faecal out put (F)	480	381	273
Assimilation (A = C-F)	2732	2126	1978
Metabolism (R = A-P)	2543	1981	1805
Assimilation efficiency (A/C × 100)	85.06	84.86	87.87
Gross growth efficiency (P/C × 100 or K_1)	5.88	5.78	7.69
Net growth efficiency (P/A × 100 or K_2)	6.92	6.82	8.75
Relative growth rate (g; P/$\bar{W}$/No. of days)	0.0102	0.0082	0.0106
Consumption/unit wt/d (g)	0.2579	0.2087	0.243

Qasim and Easterson[6] and Royan *et al.*[7] reported high conversion efficiencies in *M. monoceros* when fed with natural estuarine detritus (5% protein) and low protein pellet (20%). In the present study, however, although the protein content of the test diets was low (8-18%), the conversion efficiency was poor. The reason for this may be attributed to the protein source. Detritus is known to contain easily assimilable proteins of plant, animal and microbial origin. The low protein pellet was a mixture of animal and plant protein. In our studies, the feeds contained pure plant protein. Cowey *et al.*[8] pointed out that plant protein as such or as a mixture with animal protein gave low growth rate in plaice. They attributed it to the presence of some complex carbohydrate, resistant to enzyme action as well as capable of inhibiting protein conversion, thereby resulting in lower growth rate.

It is well known that the mangroves produce large quantities of dry organic matter which form the source of food for estuarine organisms. Schuster[9] used mangrove leaves in pond culture. In the light of the present results, it may be concluded that future experiments with decomposing mangrove vegetation would provide interesting results since associated bacterial flora of decomposing leaves would increase protein content of the plant food as well as making it into an easily assimilable form. Further, it may improve the quality of food by providing essential amino acids lacking as such in healthy (non-decomposing) leaves and by breaking down the complex carbohydrates biologically hindering with protein digestion.

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Effect of Low Oxygen Concentration on Respiratory Movements of *Balanus tintinnabulum tintinnabulum* (L.)

D G V PRASADA RAO & Y PRABHAKARA RAO
Department of Zoology, Andhra University, Waltair 530003

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At low oxygen concentrations (3, 2.5, 2 and 1.5 ml O_2/litre), hypoventilation has been observed in the respiratory movements of *B. tintinnabulum tintinnabulum*. A critical oxygen concentration is found at 3.5 ml O_2/litre below which the respiratory movements show a decline. Extremely low oxygen concentrations (1.5 ml O_2/litre) induce anoxic arrest of the respiratory movements with the complete closure of the operculum.

Ventilatory responses of animals are affected by changes in the oxygen concentrations of the external environment. Though many invertebrates exhibit hypo- and hyper-ventilation below the ambient oxygen concentration, many crustaceans show hypoventilation. Several investigators have reviewed the work on this aspect in crustacea[1-3].

Except for the work of Fox and Johnson[4] on the effect of oxygen and carbondioxide on the respiratory movements of *Balanus balanoides*, there are no other reports on this aspect in barnacles. Earlier studies on the respiration of *B. tintinnabulum tintinnabulum* are only on the oxygen consumption in relation to body size[5], oxygen concentration[6] and salinity variation[7]. *B. tintinnabulum tintinnabulum* occurs as a fouling organism infesting the submerged structures like jetties, piers and buoys in Visakhapatnam outer harbour. It is also found encrusted on the boulders in the littoral zone of the intertidal region where the oxygen concentration varies from 3.65 to 4.83 ml/litre, and it does not extend into the enclosed harbour channel where the oxygen concentration reaches low value (0.9 ml O_2/litre) due to industrial and sewage pollution. In the present investigation the effect of low oxygen concentration on the respiratory movements of *B. tintinnabulum tintinnabulum* has been studied with a view to comparing the results with barnacles and other crustacea.

B. tintinnabulum tintinnabulum were collected from the open intertidal region of Visakhapatnam. Collections were made from the same height to avoid any variation due to tide level[8]. Specimens of about the same size were chosen to eliminate the possible effect of age. They were acclimatized in the laboratory at 25°C in the filtered sea water for 12 hr. Whatman 42 filtered sea water was used for all the experiments to avoid the influence of diatoms and other algae. Salinity of the sea water used for different experiments ranged from 31 to 33‰ and the *p*H of the sea water was 8.

Respiratory movements were recorded on a Palmer Kymograph adapting the method of Ganapati and Prasada Rao[9]. Respiratory movements were studied at different oxygen concentrations, viz. 4, 3.5, 3, 2.5, 2 and 1.5 ml O_2/litre. The recording was stopped at the point where the oxygen concentration changed. Sea water samples of different oxygen concentrations were prepared by bubbling nitrogen through a gas diffuser into the sea water. They were kept in aspirator bottles with the surfaces covered with liquid paraffin. Different grades of oxygen concentrations were maintained within a variation of ±0.1 ml O_2/litre. Temperature of the sea water in the experimental bath was kept at 25 ± 0.5°C, and the surface of the sea water in the experimental bath was covered with a thin layer of liquid paraffin in order to prevent the sea water from contact with atmospheric oxygen.

A series of characteristic changes in respiratory movements have been observed when the animals were subjected to different oxygen concentrations. No marked changes have been observed in these movements at oxygen concentrations of 4.5, 4 and 3.5 ml O_2/litre (Fig. 1) and the pattern of respiratory movements is normal with no variation in the frequency (SD=0.4216). Thus the respiratory movements are independent of oxygen concentration up to 3.5 ml O_2/litre, and the 'critical oxygen concentration' for the respiratory movements is about 3.5 ml O_2/litre as shown by kymogram also in *B. tintinnabulum tintinnabulum*.

It is interesting to note that there is no hyperventilation as the rate of the respiratory movements did not increase at low oxygen concentration (3.5 ml O_2/litre). However, a hypoventilation has been observed with a decrease in the rate of respiratory movements below the critical oxygen concentration. At concentrations below the critical oxygen concentration, the respiratory movements decline in frequency. At very low oxygen concentrations (below 1.5 ml O_2/litre) a shift into anoxic arrest has been observed with the complete closure of the operculum suggesting an anaerobic shift in the metabolism.

Comparison of the results of *B. tintinnabulum tintinnabulum* with other curstaceans shows hypoventilation in this animal at low oxygen concentrations instead of a compensatory hyperventilation as in many other crustaceans. However, a similar hypoventilation has been observed by Belman[10] in the isopod *Glyptonotus* at low oxygen concentrations. Fox and Johnson[4] have observed no change in the rate of respiratory movements up to a concentration of 0.9 ml O_2/litre in *B. balanoides*. But in *B. tintinnabulum tintinnabulum*, unlike in *B. balanoides*, a definite critical oxygen concentration is observed and the anoxic stoppage of the respiratory movements at very low oxygen concentration is by complete closure of the operculum.

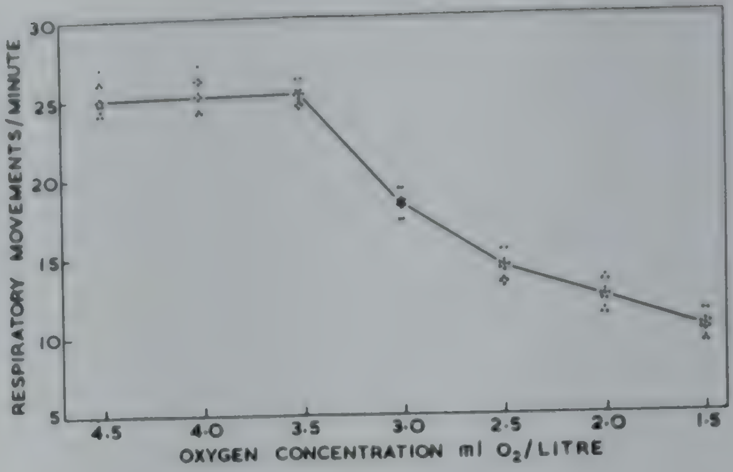

Fig. 1—Relation between oxygen concentration and the rate of respiratory movements in *B. tintinnabulum tintinnabulum*

Comparison of the results of the present investigation with that of oxygen uptake at different oxygen concentrations[6] reveals that both the processes exhibit a lowering at the same level of oxygen concentration. At low oxygen concentrations (below 3.5 ml O_2/litre) the decrease in the rate of the respiratory movements may be an associated phenomenon of the low oxygen consumption[6].

High level of 'critical oxygen concentration' observed in *B. tintinnabulum tintinnabulum* shows its less tolerance and less adaptation to low oxygen concentration and this may be one of the factors limiting its distribution in the enclosed harbour channels.

The response of respiratory movements in *B. tintinnabulum tintinnabulum* to low oxygen concentration shows 2 different phases, (i) a phase of lowering in the frequency of respiratory movements below the critical pressure and at very low concentrations (below 1.5 ml O_2/litre) and (ii) a complete shift into anaerobic state followed by the anoxic arrest of the respiratory movements by complete closure of the opercular valves.

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Occurrence of a Podocopan Ostracod *Tanella indica* sp. nov in the Marginal Water Bodies, East Coast of India

C ANNAPURNA & D V RAMA SARMA
Department of Zoology, Andhra University, Waltair 530 003

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Distinguishing characters relating to carapace and soft parts of a new podocopan benthic ostracod, *T. indica* inhabiting the shallow backwaters of Bimili, Balacheruvu and lower reaches of the Vasishta Godavari estuarine system on the east coast of India, have been described.

While investigating systematics and ecology of the benthic ostracods inhabiting marginal water bodies on the east coast of India, a new species belonging to the genus *Tanella*, a podocopan ostracod, has been encountered in the backwaters of Bimili 35 km north of Visakhapatnam, Balacheruvu tidal stream 15 km south of Visakhapatnam and in the lower reaches of the Vasishta Godavari estuary. So far only 3 species of *Tanella* are recorded[1-3].

Various ecological parameters and their range of variation prevailing at the time of collection at different areas are: water temperature, 22.8°-40°C; salinity, 0-44.35‰; dissolved oxygen, 2.9-10.97 ml/litre; and organic matter, 0.1261-3.205%.

This species occurred in all collections made in April, June, July, and September at the seaward end of the Bimili backwater and also in July, October and December collections at the seaward end of the Balacheruvu tidal stream. It was recorded in considerable numbers in June, October and November in the lower reaches of the Vasishta Godavari estuary.

Description of carapace—Carapace size: male, 0.5 mm × 0.2 mm; female, length, 0.55 mm and height, 0.25 mm.

Carapace (Fig. 1 A to C and Fig. 2 A and B) oblong and tumid, maximum height at the middle. Anterior rounded, posterior obliquely rounded and turned upwards. Dorsal margin convex, ventral margin straight. Surface sculptured by reticulations at anterior end. Anterior reticulation consists of a row of 6 deep pits. Posterior reticulation obscure with pits ranging from 3-6 arranged in groups. Anterior marginal ridges strong, and end in the ventral area. Hingement of the right valve consists of a posterior socket opening interiorly and with an intermediate crenulate ridge. Marginal area wide at the anterior end. Nature of marginal pore canals is intermediate between bifurcate and polyfurcate branching. Muscle scars arranged in a vertical row of 4 scars and a V shaped frontal scar. Sexual dimorphism strong.

Description of soft parts—Antennule (Fig. 2C) 4 jointed, ultimate podomere long and narrow with 2 claw like setae. Distal ends of 2nd and 3rd podomeres end with single claw like setae. Antenna (Fig. 2D) 3 jointed, ultimate podomere with 2 claw like setae, 1 serrate seta is situated on the margin of the podomere. Podomere (2nd) long and broad and bears 2 claws. Exopodite (spinning bristle) reaches the ends of the

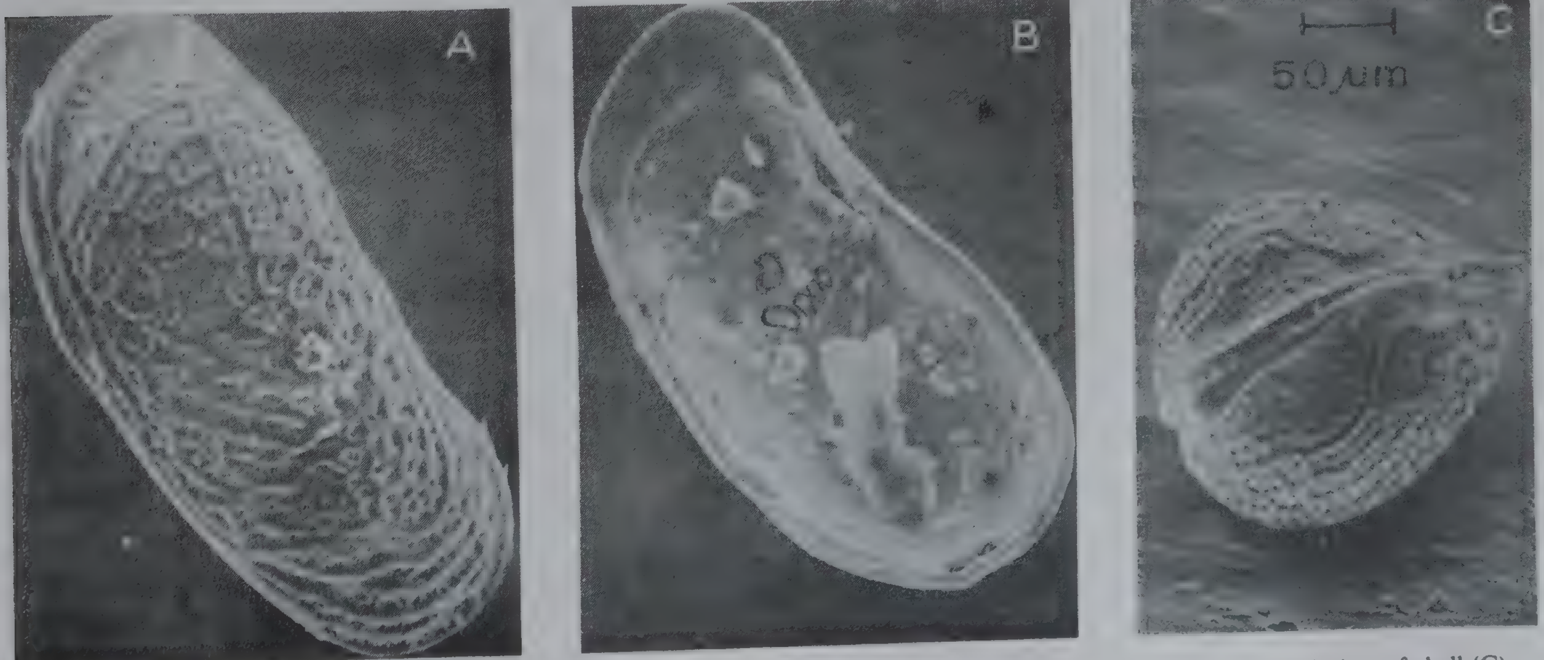

Fig. 1—Outside view of right valve (A), inside view of left valve showing muscle scars (B) and left - right dorsal view of shell (C)

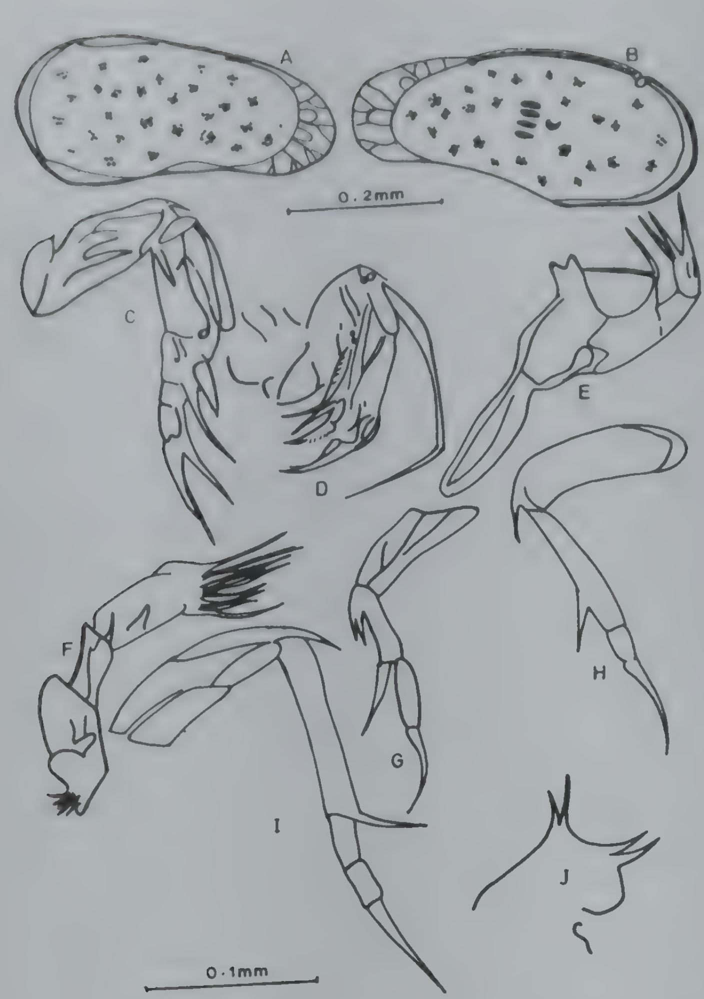

Fig. 2—Parts of *T. indica* [A, inside view of left valve showing marginal pore canals; B, inside view of right valve showing muscle scars and marginal pore canals; C, antennule; D, antenna; E, mandible with palp; F, maxilla with vibratory plate; G, first thoracic leg; H, second thoracic leg; I, third thoracic leg; and J, furcae]

distal claws. Mandible (Fig. 2E)—2 teeth placed laterally on cutting areas. Palp 3 segmented. Distal end of 2nd segment with 2 unfeathered setae, 3rd segment long and narrow with 3 setae at distal ends. Maxilla (Fig. 2F)—masticatory lobe short and broad with 5 or 6 setae. Vibratory plate long and narrow with 9 unfeathered rays. Thoracic legs (Fig. 2G-I) 4 jointed, ends with curved claws and bearing 1-3 setae on distal ends of each joint, 3 pairs of thoracic legs similar in structure. Furcae (Fig. 2J) paired and attached to the posterior end of the body.

While the description of the present species agrees with the other 3 species[1-3] in the structure of the inner lamella it substantially differs in several other characters of systematic importance such as oblong and tumid shape of carapace, strongly arched anterior marginal ridges, pits ranging from 3 to 6 arranged in groups in the obscure posterior reticulations, intermediate condition of the marginal pore canals between bifurcate and polyfurcate branching and the occurrence of additional V shaped frontal scar (Fig. 2B) which strongly warrant creation of this new species.

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Pisione oerstedii Grube, 1857 (Polychaeta: Pisionidae) from the East Coast of India, Bay of Bengal

N SIVA RAMA SARMA & P CHANDRA MOHAN
Department of Zoology, Andhra University, Waltair 530 003

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Occurrence of *P. oerstedii* from the intertidal sands of the Waltair coast is reported. A brief description of the species along with its ecology and distribution is presented.

Information on the genus *Pisione* (Polychaeta) from the Indian waters is very fragmentary. So far 8 species of this genus have been recorded from various regions[1-8]. Hartman[9] has reviewed the polychaete fauna of Indian Ocean. From the available information it is evident that *P. oerstedii* has not been reported so far from the Indian waters. The present communication reports the occurrence of *P. oerstedii* from the intertidal sands of Waltair coast along with its ecology and distribution.

While engaged in the studies of the systematics and ecology of the interstitial fauna of Waltair coast, 6 juvenile specimens of *P. oerstedii* were collected. The body of the worm was thread-like and smooth. The segments were well marked and ranged from 40-60. Reduced prostomium lacking the prostomial appendages and the acicula of the tentacular segment projecting between the bases of the palps were the characteristic features of the genus *Pisione*. Trapezoid prostomium fused with peristomium, occurrence of 3 pairs of peristomial appendages and the presence of uniramous feet with both simple and complex setae were the diagnostic features of the species *P. oerstedii*. The palps of the anterior region were mounted on globular papillae and 2 pairs of peristomial appendages were oriented as small biarticulate tentacular cirri. The uniramous feet were beset with globular cirri at their bases. Of the 2 acicula of the parapodium one was small and superior and the other long and median. Out of the 5 setae one was simple and

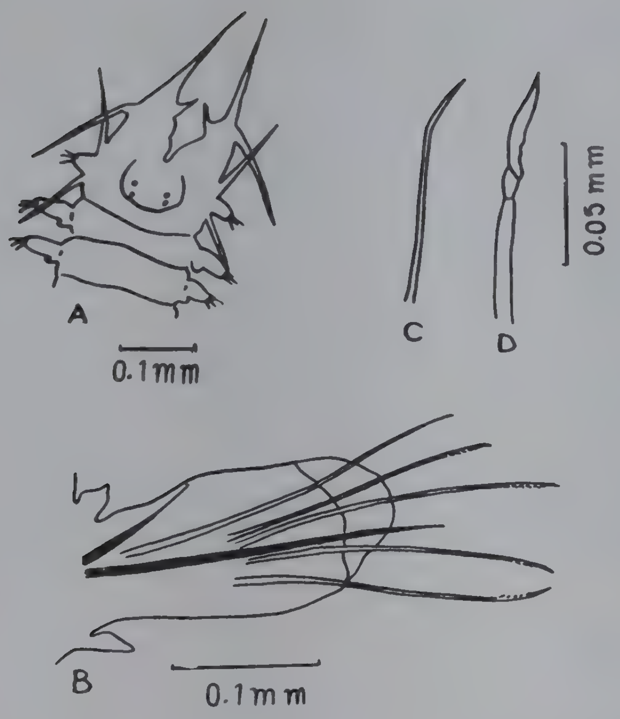

Fig. 1—*Pisione oerstedii* [A, anterior end; B, parapodium; C, simple seta; and D, compound seta]

the rest were compound with a short, falcate and unidentate terminal piece (Fig. 1). Pygidium was provided with a pair of short anal cirri.

The specimens collected from the fishing harbour area were found inhabiting mostly the mid tide level (salinity, $29.51\,^{o}/_{oo}$; dissolved oxygen, 3.92 ml/litre and temperature, 25.5°C) where the substratum is made up of coarse sand occasionally interspersed with shelly gravel. Vertically the organisms remained restricted to the upper few centimeters of the sand containing organic matter. These organisms were high in abundance only during summer months, and they were abundant in the areas where the interstitial diatoms like *Nitzschia* sp., *Coscinodiscus* sp., *Asterionella japonica* etc. were dense.

The polychaetous worms associated with *P. oerstedii* included *Prionospio cirrifera, Malacoceros indicus, Glycera dibranchiata, Pisione gopalai* and *P. complexa*.

Thanks are due to Prof. K. Hanumantha Rao, Head of the Department for providing facilities. One of the authors (NSRS) thanks the CSIR for the award of a J.R.F. Thanks are also due to their colleague Sri A.V. Raman for assistance in identification and to Dr G.C. Rao of ZSI for confirming the first record of the present species from the Indian coasts.

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Haematology of Ten Pounder, *Elops saurus* (L.), a Euryhaline Fish from Visakhapatnam Harbour

K USHA RANI & K SRINIVASA RAO
Department of Zoology, Andhra University, Waltair 530 003

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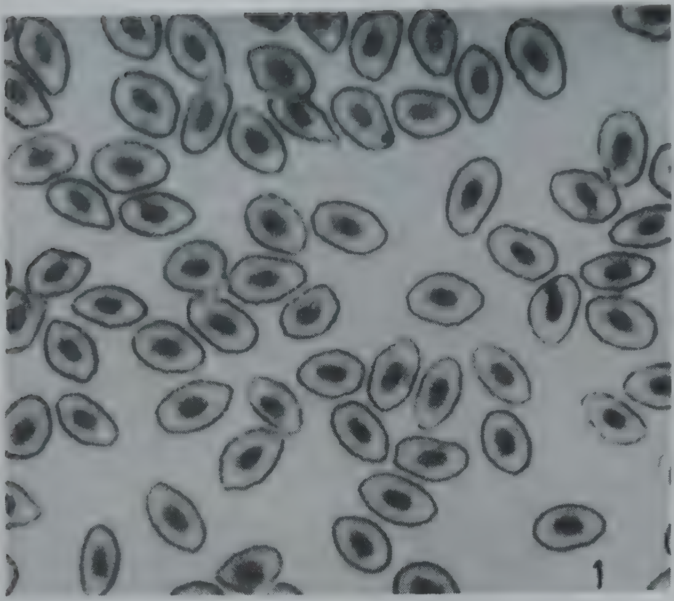
Haematological parameters like total RBC count (2.2 million/mm^3), total WBC count (0.175 million/mm^3), haemoglobin content (7.84 g/100 ml) and differential counts of various blood cell types were studied. Some fish showed deviations from the normal values and these aberrant values were found associated with anaemic condition of the fish.

Haematological studies of fishes in India are mostly limited to freshwater fishes[1-3], except a marine teleost, *Diodon hystrix*[4]. In this communication haematological parameters of the euryhaline fish, *Elops saurus*, collected from the harbour waters of Visakhapatnam are reported.

Specimens (40) ranging from 18 to 26.1 cm (total length) were collected during July to December 1977. Blood samples were collected by cardiac puncture, with heparinized syringes. Total counts of RBC and WBC were made with improved Neubauer's chamber using Shaw's diluting fluid as suggested by Hesser[5]. Total haemoglobin was determined by cyanmethaemoglobin method[6] using standards obtained from Vallabhbhai Patel Chest Institute, Delhi. Differential counts of all cell types and cytometric measurements of the erythrocytes were also made. Since there were no significant variations in the haematological parameters in relation to size, stage of maturity and season, the data were pooled, except in 3 fishes with apparently abnormal values.

Blood of *E. saurus* contains relatively larger, elliptical and nucleated erythrocytes (cytosome 12.5 × 7.2 μm; nucleus 5.3 × 4.1 μm; Fig. 1) compared to other teleosts[7]. Erythrocytes form the major component of all the cellular entities of blood whereas leucocytes constitute the minor component (Table 1). Normal mean haematological values for total erythrocyte count, total leucocyte count and haemoglobin content are also given in Table 1.

Deviations from the above normal values are observed with very low total RBC count, reduced haemoglobin content and percentage composition of RBC, in August 1977 sample. Increase in the WBC



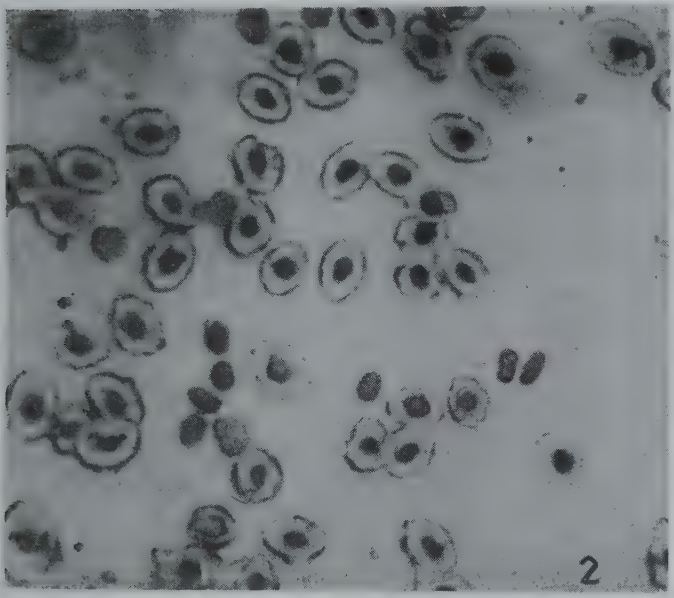


Fig. 1—Normal erythrocytes from the blood smear of healthy *E. saurus* × 600. Fig. 2—Anisocytosis of erythrocytes and a few immature and degenerating erythrocytes from the blood smear of anaemic *E. saurus* × 600

content, the ratio of the total WBC to RBC count along with slight increase in MCH (mean corpuscular haemoglobin) are also observed in the aberrant sample (Table 1). Such marked differences from normal values are also reported by Smith[8] in his experiments on Coho salmon regarding anaemia due to deficiency of folic acid in the diet. The apparent increase in the total WBC count observed in the aberrant sample is in conformity with the observations of Mc Knight[9]. The values observed in the aberrant sample thus indicate anaemic condition of the fish.

Comparison of differential counts between normal and anaemic samples shows some significant changes in the leucocyte composition (Table 2). Granuloblasts (neutrophiloblasts) and small haemoblasts, absent in the normal blood samples, are observed in the anaemic samples. The other prominent changes include increase of neutrophils and decrease of thrombocytes in the anaemic fish. A slight increase in the erythroblast content is also noticed.

Table 1—Normal and Aberrant Values of Blood Parameters of *E. saurus*

		Normal values (N = 37)	Aberrant values (N = 3)
RBC total count (million/mm^3)	Range	1.95-2.85	1.19-1.31
	Mean	2.2	1.24
	SD	0.2	0.07
WBC total count (million/mm^3)	Range	0.1 -0.25	0.21-0252
	Mean	0.175	0.23
	SD	0.035	0.02
Haemoglobin content (g/100 ml)	Range	5.86-10.2	4.53-5.42
	Mean	7.84	4.85
	SD	1.47	0.49
WBC/RBC		0.081	0.189
RBC (%)		92.63	84.13
WBC (%)		7.37	15.87
MCH (pg)		35.64	39.24

N = Number of fish

Table 2—Differential Counts (percentages) of Various Blood Cell Types in *E. saurus*

Cell type	Saunders[7]	Present study	
		Normal samples	Aberrant sample
	Erythrocyte series		
Mature erythrocytes	96.7	99	98
Erythroblasts	3.3	1	2
	Leucocyte series		
Thrombocytes	52.3	49.8	40
Small lymphocytes	35	30.5	30
Large lymphocytes	—	6.8	6
Monocytes	—	2.65	2
Neutrophils	5.7	8.3	12
Eosinophils	5.7	1.6	1
Basophils	—	0.25	—
Macrophages	—	0.1	—
Small haemoblasts	1.3	—	1
Neutrophiloblasts	—	—	8

Differential counts of various blood cell types observed in the present study and those by Saunders[7] for *E. saurus* (Table 2) show the occurrence of large lymphocytes, monocytes, basophils and macrophages in the former only.

RBC of fishes with low activity are reported to be generally of larger size with low total count and reduced haemoglobin content[10,11]. Compared to other teleosts[7] the large size of RBC with low total count (2.2 million/mm^3) and reduced haemoglobin content (7.84 g/100 ml) as observed in *E. saurus* is indicative of its low activity.

Presence of small haemoblasts, erythroblasts, and granuloblasts along with some degenerating blood cells and debris observed in the present study are usually associated with pathological conditions such as anaemia[12] or infection[9]. The observed aberrant values in *E. saurus* seem to be due to anaemic condition of the fish which is further supported by the presence of the immature blood cells. An important change in the erythrocyte morphology 'anisocytosis' (dissimilar erythrocytes), is also observed in the present study (Fig. 2) which is in conformity with the report of Smith[8].

The authors thank Prof. K.H. Rao, Head of the Department for the facilities and one of them (KUR) thanks the CSIR for the financial assistance.

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Characterization of Marine Food Borne Pathogen, Vibrio parahaemolyticus, Isolated from Freshwater Fishes—R. Natarajan, G. Balakrish Nair & Martin Abraham, Centre of Advanced Study in Marine Biology, Annamalai University, Parangipettai 608502

Trace Metals in Zooplankton from the Bay of Bengal—M.D. George & Tariq W. Kureishy, National Institute of Oceanography, Dona Paula, Goa 403004

Colonization of Graded Sand by the Interstitial Fauna of Monazite Sands—K.C. Rajan & N. Balakrishnan Nair, Department of Aquatic Biology and Fisheries, University of Kerala, Trivandrum 695007

Distribution of Organic Carbon in Sediments of the North West Continental Shelf of India—A.L. Paropkari, National Institute of Oceanography, Dona Paula, Goa 403004

Biochemical Studies on Some Tropical Estuarine Zooplankton Species—M. Madhupratap, P. Venugopal & P. Haridas, National Institute of Oceanography, Dona Paula, Goa 403004

Energy Value of Suspended Detritus from Some Stations along the West Coast of India—Sumitra-Vijayaraghavan, M.V.M. Wafar & L. Krishna Kumari, National Institute of Oceanography, Dona Paula, Goa 403004

Energy Content of the Wedge Clam, Donax incarnatus Gmelin—T. Balasubramanian, Sumitra-Vijayaraghavan & L. Krishna Kumari, National Institute of Oceanography, Dona Paula, Goa 403004

Pollution Status of the Cochin Beach—P.S. Gore, O. Raveendran & R.V. Unnithan, National Institute of Oceanography, Regional Centre, Cochin 682018

Organic Matter in Sediments Off Northeastern Andamans—M. Rama Murty, K.V. Venkatesh & C.V.L. Narasimham, Geological Survey of India, 4, Chowringhee Lane, Calcutta 700016

Hydrography, Chlorophyll & Plankton of the Kuwaiti Coastal Waters—P.G. Jacob, Mazin A Zerba & V. Anderlini, Marine Pollution Programme, Environmental & Earth Sciences Division, Kuwait Institute for Scientific Research, P.O. Box 12009, Safat, Kuwait

Chaetognatha from a Sector in the Bay of Bengal—N. Anbusaravanan, K. Krishnamurthy & K. Balasubrahmanyan, Centre of Advanced Study in Marine Biology, Annamalai University, Parangipettai 608502

Marine Microplankton from Sierra Leone (West Africa)—A.A. Aleem, Institute of Marine Biology & Oceanography, University of Sierra Leone, Sierra Leone

Geomorphology of the Gulf of Kutch—B.G. Wagle, National Institute of Oceanography, Dona Paula, Goa 403004

Faunal Composition in Polluted Nearshore Environment—P. Gopala Menon, M. Madhupratap, P. Haridas, P. Venugopal & T.S.S. Rao, National Institute of Oceanography, Regional Centre, Cochin 682018

Ecology of Magelona cincta Ehlers, 1908 (*Polychaeta : Magelonidae) in the Vasishta Godavari Estuary, India*—D. Srinivasa Rao & D.V. Rama Sarma, Department of Zoology, Andhra University, Waltair 530003

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Geomorphology of the Gulf of Kutch

B G WAGLE
National Institute of Oceanography, Dona Paula, Goa 403 004

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Based on the analyses of 678 km of echosounding carried out during 2nd cruise of *RV Gaveshani* it is found that a prominent geomorphic feature demarcated in the Gulf of Kutch is the axial E-W running narrow depression with scarps and a very rough to rugged surface. The sea bed of the Gulf is divided into 3 distinct morphologic units—even, uneven and rough. The major axial depression may have been the result of scouring action by bottom currents on a channel following a tectonic feature. The even topography is originated due to the recent sediments brought down by rivers. The uneven and rough surface may owe its origin primarily to tectonic instability later accentuated by abrasion and erosion due to high velocity tidal currents. This surface probably coincides with a tectonic zone of weakness where the abrasion and erosion can easily carve out the present irregular topography. Finally it is possible that the sea surface was exposed during lowered sea levels and the topography recorded may represent the relict topography.

RV Gaveshani carried out a reconnaissance marine geological survey of the Gulf of Kutch in March 1976 (Fig. 1). The survey consisted of echosounding, shallow seismics and magnetics followed by bottom sampling by grabs, snapper and dredgers. In addition hydrographic casts, current and sound velocity measurements were also made at several stations. The survey tracks commenced as close to the shore as the depths of water and sea conditions permitted and were run across the Gulf to obtain the best possible coverage. The positions were obtained by radar fixes. Echosounding was continuously carried out on a Kelvin and Hughes MS-45 (30 kHz) or a Simrad EQ echosounder along tracks totalling 678 km.

The Gulf of Kutch because of its peculiar shape is marked by high tides, the average tidal range at Okha and Kandla is 3.06 and 5.89 m respectively. The associated tidal currents are fairly strong, reaching 4-5 knots in the open Gulf near the mouth. High tidal range and associated tidal currents are an effective geological agents and would have played a significant role in sedimentation and shaping the floor of the Gulf.

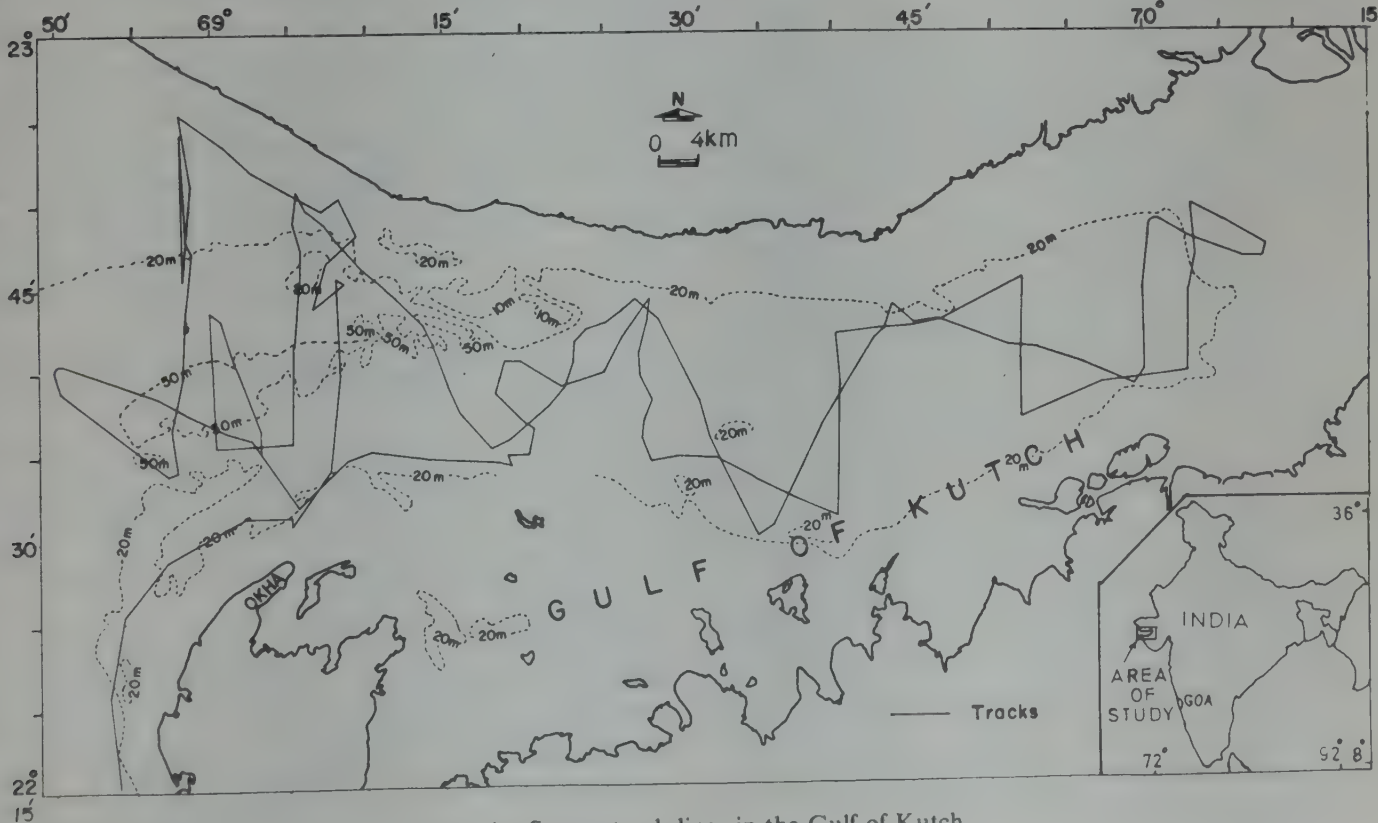

Fig. 1—Survey track lines in the Gulf of Kutch

Geological Setting

The Gulf of Kutch lies between the northern coast of Kathiawar peninsula and the southern coast of Kutch district. The southern shores of the Gulf are marked by a low level coastal plain with indentations, deep inlets, a number of offshore islands and several river mouths. The northern shores of the Gulf is fronted by numerous sandy shoals. On the mainland as well as the islands marshes exist side by side with occasional rocky cliffs 2 to 3 m high. Ahmad[1] considers these features to be indicative of a submerged coast line. Coral reefs and oyster beds are also reported near the islands[2].

The geomorphological studies of Kutch show that the present topography is very young and that there has been very late uplift. Four plains of erosion have been recognised in the Kutch, viz. Paleocene, post-Paleocene, post-Miocene and early Quaternary[3].

The Gulf is bounded on the south by the Deccan Traps which lie disconformably over the Mesozoic sediments and are in turn overlain by Paleocene volcanoclastic sediments with a disconformity[4]. On the northern side of the Gulf in the interior Kutch the pre-Cambrians are exposed in patches and these are overlain by a complete sedimentary sequences from Jurassic to Pleistocene. The Jurassics out crop in 3 E-W trending anticlinal ridges, cover a large area and their thickness is estimated to be 1950 m. The overlying marine Tertiary formations represent a shelf facies and attain a thickness of 600 m in the southwest[5]. These are bordered to the south by Deccan Traps while on the north lies the saline marsh of the Rann of Kutch.

Results and Discussion

Sediment distribution in the Gulf of Kutch—Extensive occurrences of rock are reported from the Gulf of Kutch especially in the central part, sediment is largely confined to the margins of the Gulf. Apparently the high tidal ranges in the Gulf generate powerful currents which are not conducive to sediment deposition. Petrographic and foraminiferal studies of the rock samples indicate that these consist of calcareous sandstones. These sandstones extend from the mouth to the centre of the Gulf and cover a large part of the seabed[6]. Recent study of the Gulf of Kutch sediments[7] reveals that the sediments consist of light grey silt and clay and patches of fine sand. The sediments are poor to extremely poor sorted, the skewness is highly variable and there is no relation to either the texture or mean size of the sediment.

Geomorphology—The Gulf of Kutch is aligned approximately E-W; it is about 50 km wide at the entrance with the width decreasing gently eastward along its length till about 70°20′ E where it starts abruptly narrowing. The southern coast is fringed by numerous dead coral reefs, islands and extensive mud flats which dry at low tide. In contrast, the northern coast is fringed by tidal flats only. At the head of the Gulf is the Rann of Kutch, a desiccated region, which is inundated during the SW monsoon. A number of prominent shoals (Ranwara, Lushington, Gurur, Samiyani) are present in the Gulf. These features could be due to resistant rocks capping on topographic highs remnant from an earlier phase of terrestrial erosion or to the structural highs in the bedrock or a combination of both.

Hydrographic charts of the Gulf and a study of the echograms of Cruise II of *RV Gaveshani* indicate that the Gulf is relatively shallow basin and the maximum depth recorded is about 70 m. The topography is very irregular for about 75 km from the entrance to the central Gulf; further east the depths decrease gradually towards the head and the bottom changes from rock, sandy clay to clayey silt.

A number of major geomorphic features can be identified in the Gulf. The prominent among these is an elongated ENE-WSW trending depression with very steep slopes and very rough to rugged surface extending from the entrance to the Ranwara shoals. Since the depression approximately follows the axis of the Gulf this may be a deep tidal scour channel or a channel following a tectonic feature. Depths >60 m are found within this channel and the deepest water is found SW of Ranwara shoals. Similar though smaller depressions lie within the 50 m isobath between the major depression and Ranwara shoals. A number of scarps (Fig. 2) with a relative elevation of 6 to 32 m are seen at the sediment free seabed of the Gulf. These scarps may extend towards the head of the Gulf buried in sediments. Since the tracks were widely spaced the trend of these scarps can be generalized on the basis of trend of the 20 and 50 m contours on the chart. On this basis it is inferred that the trend of these scarps is E-W and WNW-ESE which coincides with those of the major lineaments and major faults and regional strike of the area. The scarps may represent fault scarps forming the walls of a channel in the bed rock—perhaps formed due to tectonic instability during quaternary sea level fluctuations later accentuated by tidal scour.

In addition to these, other prominent geomorphic features observed are extensive eroded terraces with relatively flat floor (Fig. 3, profile e), domal smooth surfaces (Fig. 3, profile d), and sharp pinnacles of 10 to 25 m height.

Based on the study of echograms the floor of the Gulf can be divided into 3 distinct morphologic units: even, uneven and rough (Fig. 4). The region of even topography has very little or no variations (<2 m), typical of sediment covered seabed (Fig. 3, profile a). The area covering the eastern margins of the Gulf

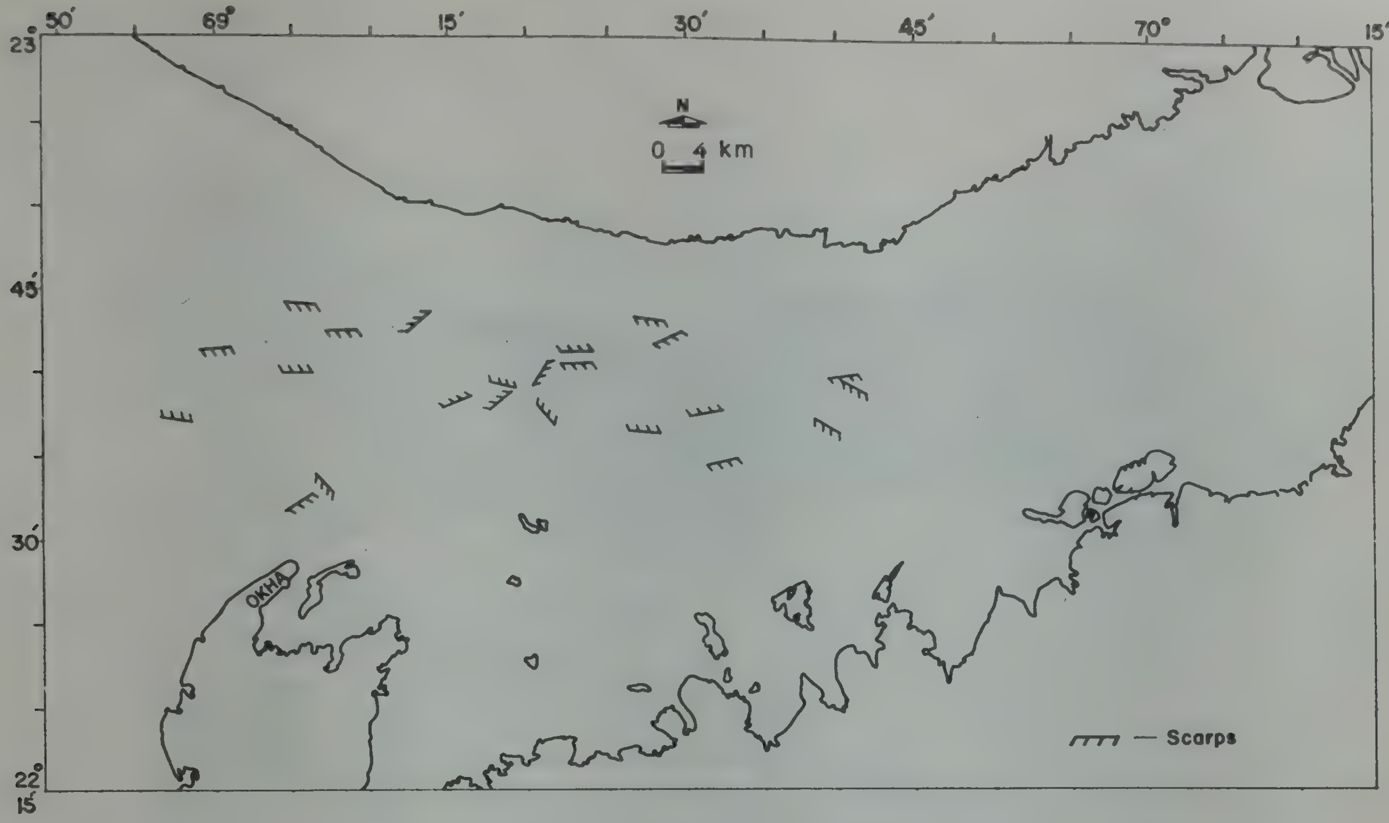
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Fig. 2—Location of surface scarps

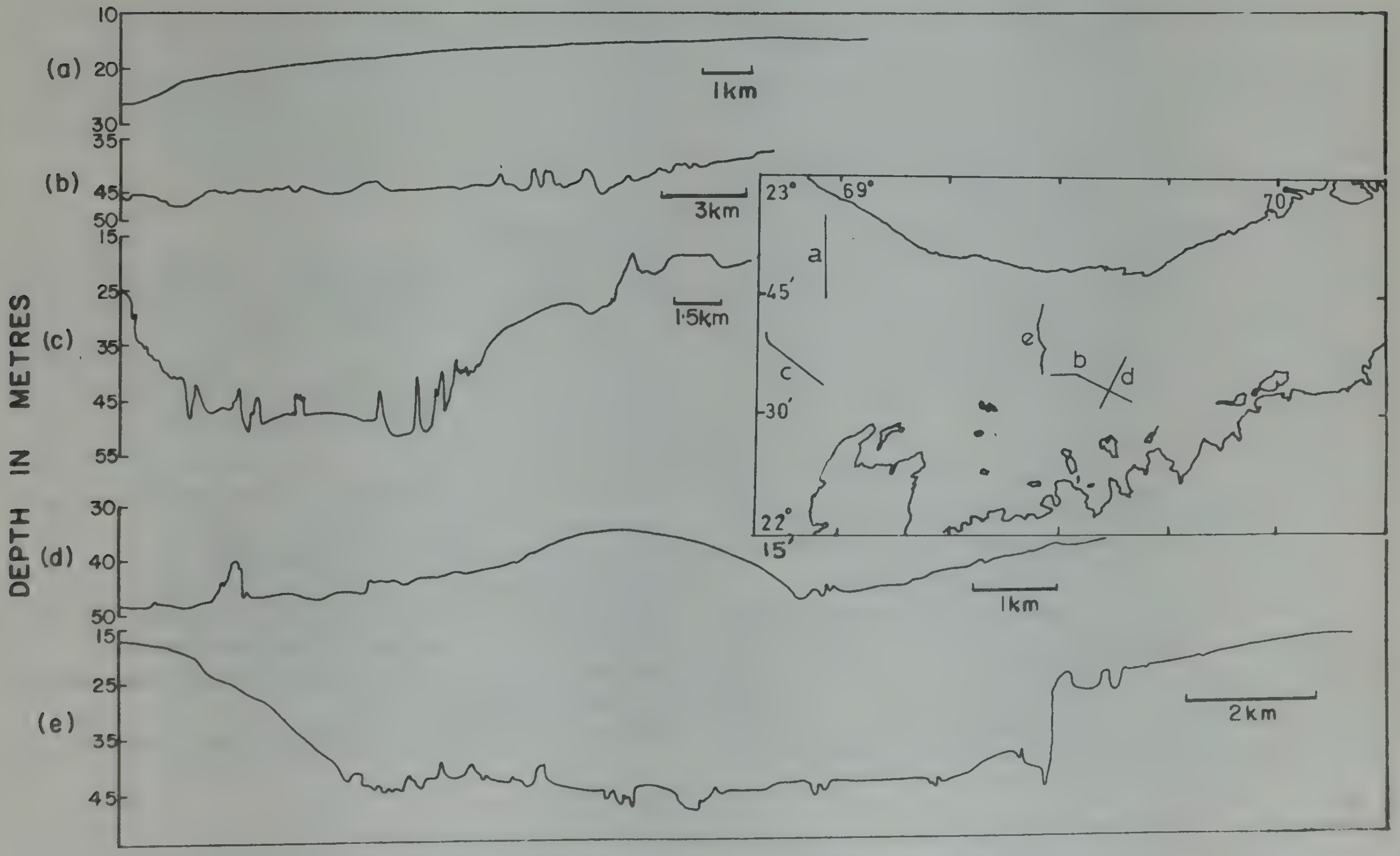

Fig. 3—Profiles across the Gulf of Kutch

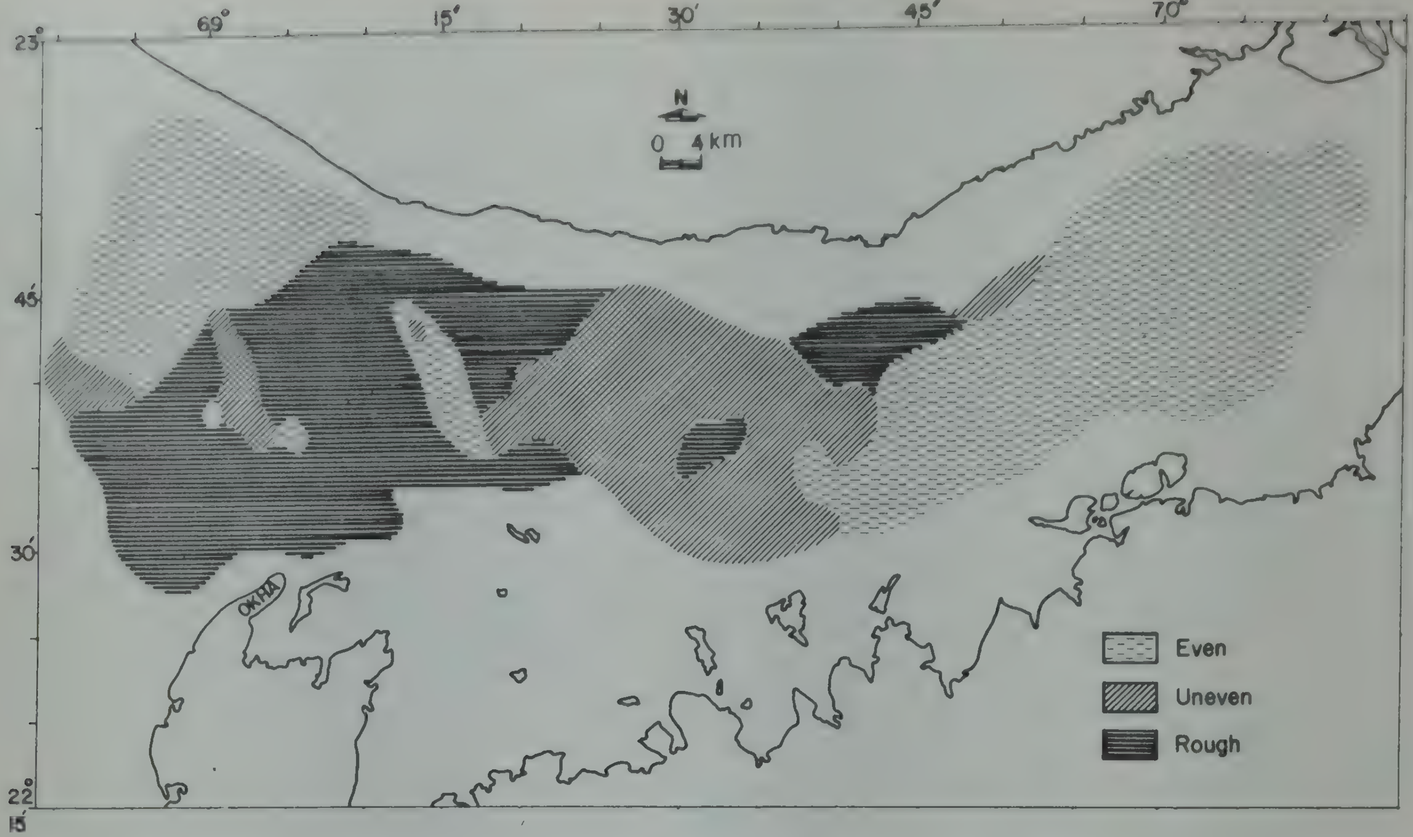

Fig. 4—Gross geomorphic subdivisions of Gulf of Kutch

extending from the north of Sikka Creek to the head of the Gulf and the northern margins are marked by even topography. The region of even topography is flat, gentle and smooth. The flatness of the surface is attributed principally to the land derived sediments masking the underlying topography. In the region of uneven topography the variations range approximately from 2 to 5 m (Fig. 3, profile b) and in the region of rough topography these range up to 25 to 30 m. The seabed in the area of rough topography consists of sharp pinnacles, ridges, valleys, etc. (Fig. 3, profile c). The region of rough topography extends from the southern side of the entrance to the Gulf to a distance of about 50 km. In the central part of the Gulf the topography is uneven with a small patch of rough surface. The distribution of uneven and rough topography mainly coincides with the area where rock is exposed on the seabed which extends to a distance of about 75 km in the central part of the Gulf.

The uneven and rough surface may owe their origin primarily to tectonic instability later accentuated by abrasion and erosion due to high velocity tidal currents which not only act as strong abrasive agents but at the same time create the non-depositional environment. This surface probably coincides with a tectonic zone of weakness where the abrasion and erosion by water could have easily carved out the present irregular topography. Finally it is possible that the sea surface is exposed during lowered sea levels and the topography recorded may represent the relict topography formed during the periods of lowered sea level.

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Distribution of Organic Carbon in Sediments of the North Western Continental Shelf of India

A L PAROPKARI
National Institute of Oceanography, Dona Paula, Goa 403 004

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Organic carbon in the sediments varies from 0.24 to 2.42% (av. 0.95%) which is far below the world average for the nearshore sediments. Fine grained terrigenous sediments of the shelf off Saurashtra coast and those in the inner shelf between Bombay and Port Dabol are characterised by relatively high organic carbon content ($>1\%$); fine grained sediments of the inner shelf between Gulf of Cambay and Bombay and the shelf between Indus canyon and Gulf of Kutch and the coarse grained carbonate relict sediments on the outer shelf are characterised by low organic carbon content ($<1\%$). Differences found in the organic carbon contents of the fine grained sediments of different regions can be traced mainly to the differences in the productivity of the overlying waters. Although in the outer shelf regions also, areas of high and low productivity are encountered, the low organic carbon content in these sediments appears to be due to a combination of several factors—coarse grained nature of the sediments, relatively low rate of sedimentation and lack of enough fine grained terrigenous material for the protection and preservation of organic matter in the sediments. The generally low organic carbon content recorded in this area when compared to world average for the shelf sediments, can be attributed to the oxidation because of high dissolved oxygen content of bottom water or grazing by zooplankton and other higher organisms.

During the cruises of *INS Darshak* (December 1973-May 1974) in the north eastern Arabian Sea, bottom sediment samples were collected from 14 sections normal to the coast (90 stations) on the continental shelf between Indus canyon in the north and Port Dabol in the south. Samples from 76 stations only were analysed for organic carbon content. The samples were collected between 20 and 100 m depth while 1 sample was collected from 250 m depth using a La Fond-Dietz snapper.

The present study of distribution of organic carbon in the sediments forms a part of the comprehensive study of the geochemistry of these sediments at the Institute. The results obtained are discussed in relation to the distribution of sediments and the hydrographic features. The distribution of organic matter and $CaCO_3$ in the sediments of the shelf has been described earlier but all the previous studies are based on limited samples[1-8]. Rao[9] has studied in detail the distribution of the $CaCO_3$ in the study area and his results are used here to depict the nature of the sediments.

Methods

A portion of representative sediment sample from each station was washed free of chloride with distilled water, dried at 60 to 70° and pulverised. An aliquot of this powder was taken and organic carbon determined following the method of EL Wakeel and Riley[10].

Results and Discussion

Organic carbon and the calcium carbonate contents at each station are shown in Fig. 1, while the texture[11] of the sediments is shown in Fig. 2. The following observations are made from Fig. 1: (i) Organic carbon content in the sediments varies from 0.24 to 2.24% corresponding to 0.42 to 3.86% of organic matter. (ii) Average organic carbon content of 0.95% corresponds to only 1.64% organic matter which is far below the world average of 2.5% for the nearshore

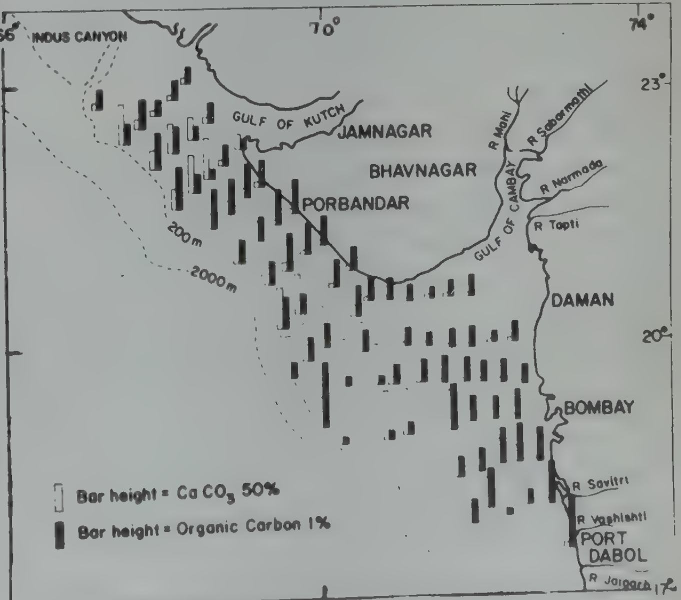

Fig. 1—Percentages of $CaCO_3$ (after Rao[9]) and organic carbon in the shelf sediments

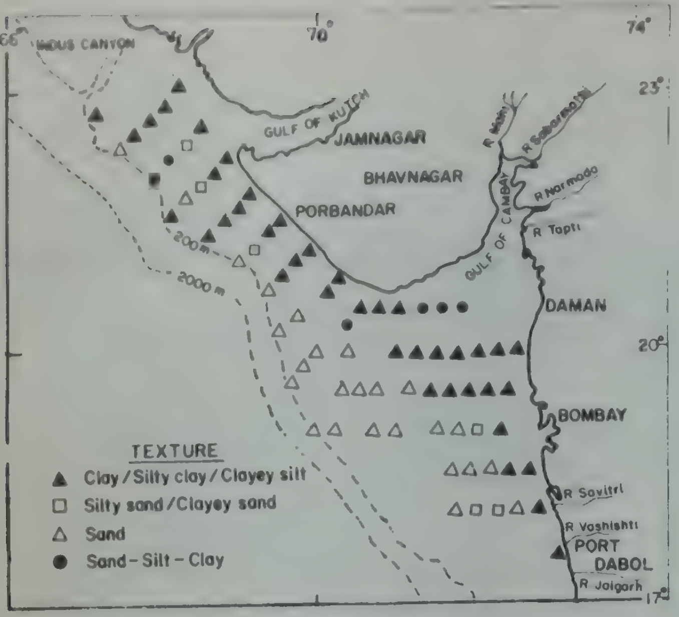

Fig. 2—Texture of the sediments (the nomenclature used is that of Shepard)

Table 1—Primary Productivity at Different Stations

Region	No. of stations	Range values of column productivity* mgC/m²/day
Shelf between Indus canyon and Gulf of Kutch	3	234-546
Shelf off Saurashtra	3	1036-2666
Shelf between Gulf of Cambay and Bombay		
Inner shelf	3	382-558
Outer shelf	4	983-1339
Shelf between Bombay and Port Dabol		
Inner shelf	2	1162-1577
Outer shelf	4	109-243

*Radhakrishna[14]

sediments[12]. (iii) Organic carbon content of the sediments indicates a definite relationship with the texture and depth. With a few exceptions, high calcium carbonate coarse grained sediments, sands and silty or clayey sands of the outer shelf (> 60 to 65 m water depth) are characterised by a low organic carbon content (< 1%). As against this the fine grained sediments off the Saurashtra coast and those of the inner shelf region between Bombay and Port Dabol are characterised by a higher organic carbon content (> 1%) while those in the other regions, i.e. the sediments of the shelf between Indus Canyon and Gulf of Kutch and the inner shelf between Gulf of Cambay and Bombay are characterised by low organic carbon content (< 1%).

The factors that favour a high organic carbon content in bottom sediments are: (i) abundant supply of organic matter in the overlying waters, (ii) relatively rapid accumulation of fine grained terrigenous inorganic matter, and (iii) low oxygen content of the bottom waters[13].

Before explaining the variations in the organic carbon content in the sediments it would be worth while to examine the above factors in the area.

Organic production—Primary productivity was measured by ^{14}C technique in 19 stations on the shelf (Table 1). The regional variations in the primary production rates are clearly seen. The waters of the shelf off Saurashtra coast, the outer shelf off Bombay and the inner shelf between Bombay and Port Dabol are characterised by high productivity while the other regions are characterised comparatively by low productivity.

Rates of terrigenous sedimentation—Rates of sedimentation for the western shelf are not known. However, distribution patterns of the sediments, i.e. the presence of fine grained sediments with low $CaCO_3$ in the inner shelf region and the high calcium carbonate coarse-grained relict sediments in the outer shelf region, suggest that the inner shelf is characterised by comparatively higher rates of sedimentation than the outer shelf. Murty *et al.*[1] described the fine grained sediments of the inner shelf between Port Dabol and Saurashtra as mostly composed of terrigenous material. The distribution of calcium carbonate indicates that the outer shelf between Gulf of Cambay and Port Dabol is relatively free from terrigenous sedimentation.

Dissolved oxygen in bottom waters—From the distribution of dissolved oxygen in bottom waters (about 5 m above the sea bottom)[15] it is seen that (1) the waters of the inner shelf between Bombay and Gulf of Cambay and the shelf off Saurashtra coast and further north are characterised by higher values of dissolved oxygen, (2) the distribution is patchy and the concentration varies from 1 to 4 ml/litre in the waters of inner shelf between Bombay and Port Dabol, and (3) the waters of large area of the outer shelf between Gulf of Cambay and Port Dabol are characterised by oxygen concentrations of < 1 ml to 1-2 ml/litre dissolved oxygen while in a small portion the dissolved oxygen increases to 2-3 and 3-4 ml/litre.

Distribution of organic carbon in the sediments of the inner shelf extending from Port Dabol to Gulf of Cambay and the shelf off Saurashtra and Kutch indicates a relationship with the productivity of waters. The regions of higher productivity are underlain by sediments with higher organic carbon content while the regions of comparatively low productivity are underlain by sediments with a low organic carbon. In view of the similar texture of the sediments and the high dissolved oxygen content of waters, the differences in the organic carbon content of the fine grained sediments of the inner shelf could only be attributed to the differences in productivity of the waters. The outer shelf is characterised by areas of high and low productivity and the bottom waters to a large extent by lower concentrations of dissolved oxygen. However, the outer shelf sediments are marked by uniformly low values of organic carbon. Because of low sedimentation rates it is possible that the organic matter produced is oxidised in the water column itself. This is partly supported by the high nutrient content in the bottom waters of the region[16].

Comparative study of the organic carbon of these sediments with those of the areas such as southern half of the western continental shelf of India[1], continental shelf of the west coast of Africa[17] and the continental shelf off Peru coast[18] which have been associated with strong upwelling and high biological productivity, has indicated that the organic carbon content values of the sediments of the investigated area are far less than the values reported from other 3 areas. This low organic carbon content could be due to oxidation of the organic matter because of high dissolved oxygen content or grazing by zooplankton and other higher organisms. The latter is more probable in view of the higher zooplankton biomass recorded in this region[19]. The fact that beneath the biologically productive surface waters there could be sediments with little organic matter is well exemplified by the studies of Summerhayes *et al.*[20] on the sediments of Southeastern Brazil, where absence of organic matter in the sediments was attributed to the high degree of oxygenation of upwelled water.

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Phosphorus Distribution in the Modern Deltaic Sediments of the Cauvery River

P SERALATHAN & A SEETARAMASWAMY
Department of Geology, Andhra University, Waltair 530003

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Distribution of phosphorus in 144 clay fractions of the sediments from fresh water river channel, estuarine, tidal channel, mangrove,swampy and marine environments of the Coleroon River, major distributary of Cauvery, has been presented. Marine zone has the highest phosphorus concentration (av. 0.223 %) and the river channel has the lowest (av. 0.152 %). Studies on interrelationships between phosphorus and organic matter, iron and calcium reveal that phosphorus is fixed mainly as organic phosphate and ferricphosphate in the deltaic sediments of the Cauvery River. Phosphorus contribution from this river to Bay of Bengal is significant.

Surfacial and nearshore sediments of the Cauvery Delta have not been studied except for grain size[1] and geochemistry[2]. Murty and Reddy[3] have reported the phosphorus content of deep marine facies off Cauvery Delta. Detailed sampling has been carried out during the post-flood season (1976-1977) in different environments and the results are reported here along with the relationships obtained between phosphorus and organic matter, total iron and calcium.

Description of Area

The Cauvery River has a drainage of about 87900 km^2 and it flows over 800 km on the southern most Peninsular India before falling into the Bay of Bengal. Maximum discharge of this river is 20950 million m^3 (ref. 4). The estuary has a maximum depth of about 12 m in summer. The tidal range is about 1 to 1.2 m. The tidal channels branching from the Coleroon estuary have at some places width 160 m. They are often shallow (2 to 3.5 m). The mangrove and swamps extend to about 15 km from the Coleroon estuary to the Vellar estuary (maximum width 6 km). In the marine zone the 5, 10 and 20 fm contours lie very close to Coleroon mouth indicating the steeper slope of the shelf, than the shelf on either side ofthe river mouth.

Materials and Methods

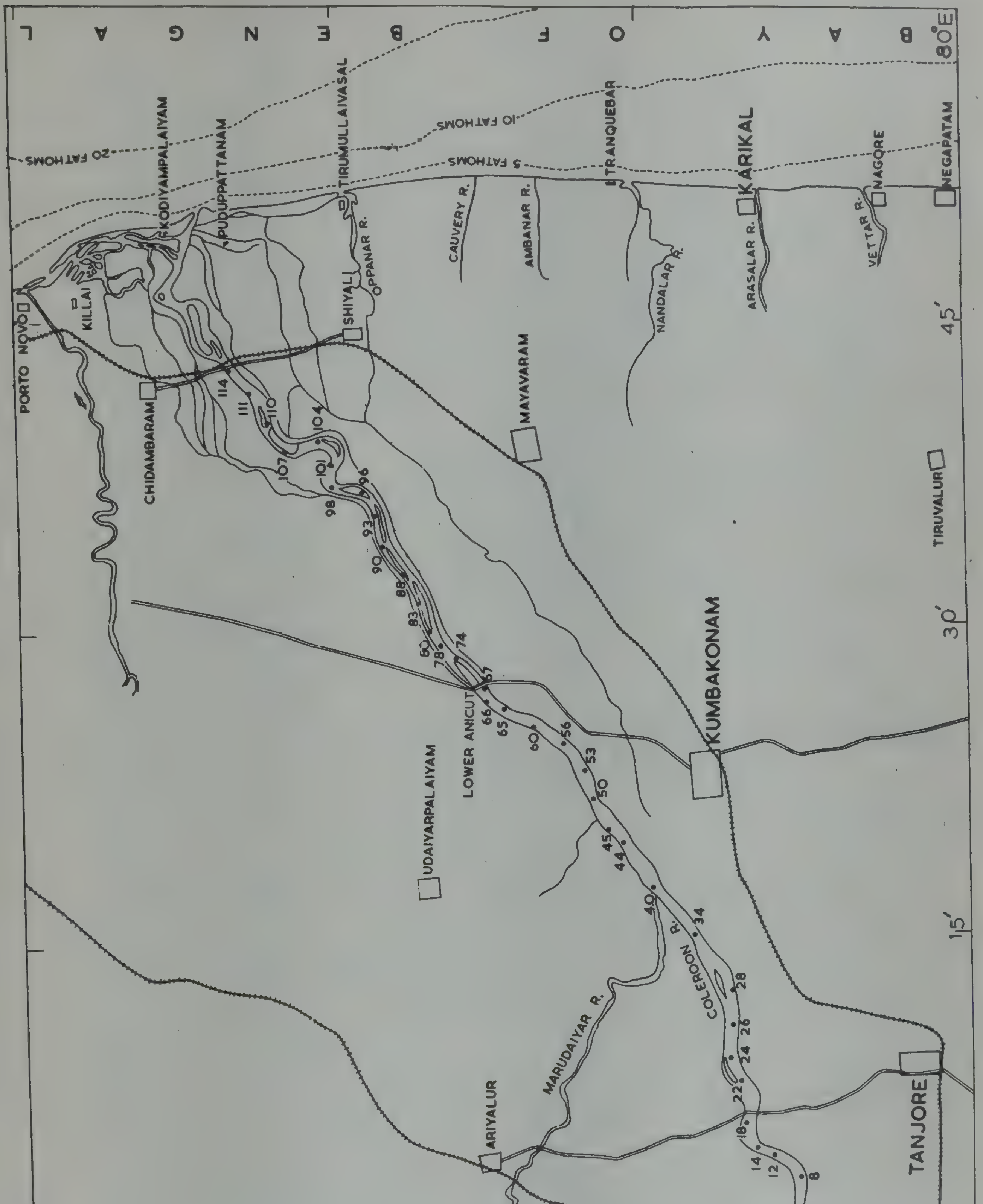
Station locations are shown in Figs 1 and 2. Samples were collected using La Fond Dietz snapper. In the marine environment samples were collected to a maximum depth of 17 fm. Clay fractions were separated from the bulk samples by the settling velocity principle[5]. Quantitative determination of phosphorus[6], total iron[7], organic matter[8] and calcium[9] was done.

Results and Discussion

The results are presented in Table 1. The following generalisations can be made in regard to the distribution of phosphorus: (1) The fresh water river channel has the lowest concentration of phosphorus (av. 0.152%). But 0.172, 0.17, 0.175 and 0.194% respectively in estuary, mangrove, tidal channel and swampy environments indicate a possible marine influence. (2) Highest concentration in marine environment is due to the cumulative effect of detrital phosphate and high organic productivity. (3) In general the phosphorus content shows a positive relationship with organic matter and total iron content; relatively it has stronger relationship with the former. (4) Calcium shows a positive relationship with phosphorus in river, estuarine and marine environments.

The important conditions that might have facilitated the formation of marine sediments rich in phosphorus in the study area are high content of dissolved phosphate in the overlying waters, and concentration of phosphorus by the organisms and their sinking to the bottom after death.

According to Bushinski[10], the waters rich in phosphate, essential for the intense development of organic life may come either from land through rivers or from deeper parts of the sea through upwelling; the river derived phosphorus is immediately assimilated by plankton and subsequently deposited on the bottom, very little being carried away to the deeper sea. In view of the above, the observed high phosphorus content in the nearshore bottom sediments off Cauvery Delta may be due to the entrapment of the river derived phosphorus through assimilation and subsequent deposition by the profuse growth of organic life,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KILLAI
KODIYAMPALAIYAM
PUDUPPATTANAM
TIRUMULLAIVASAL
SHIYALI
OPPANAR R.
CAUVERY R.
AMBANAR R.
TRANQUEBAR
NANDALAR R.
KARIKAL
ARASALAR R.
NAGORE
VETTAR R.
NEGAPATAM
CHIDAMBARAM
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KUMBAKONAM
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UDAIYARPALAIYAM
COLEROON R.
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Fig. 1—Sampling locations in river channel

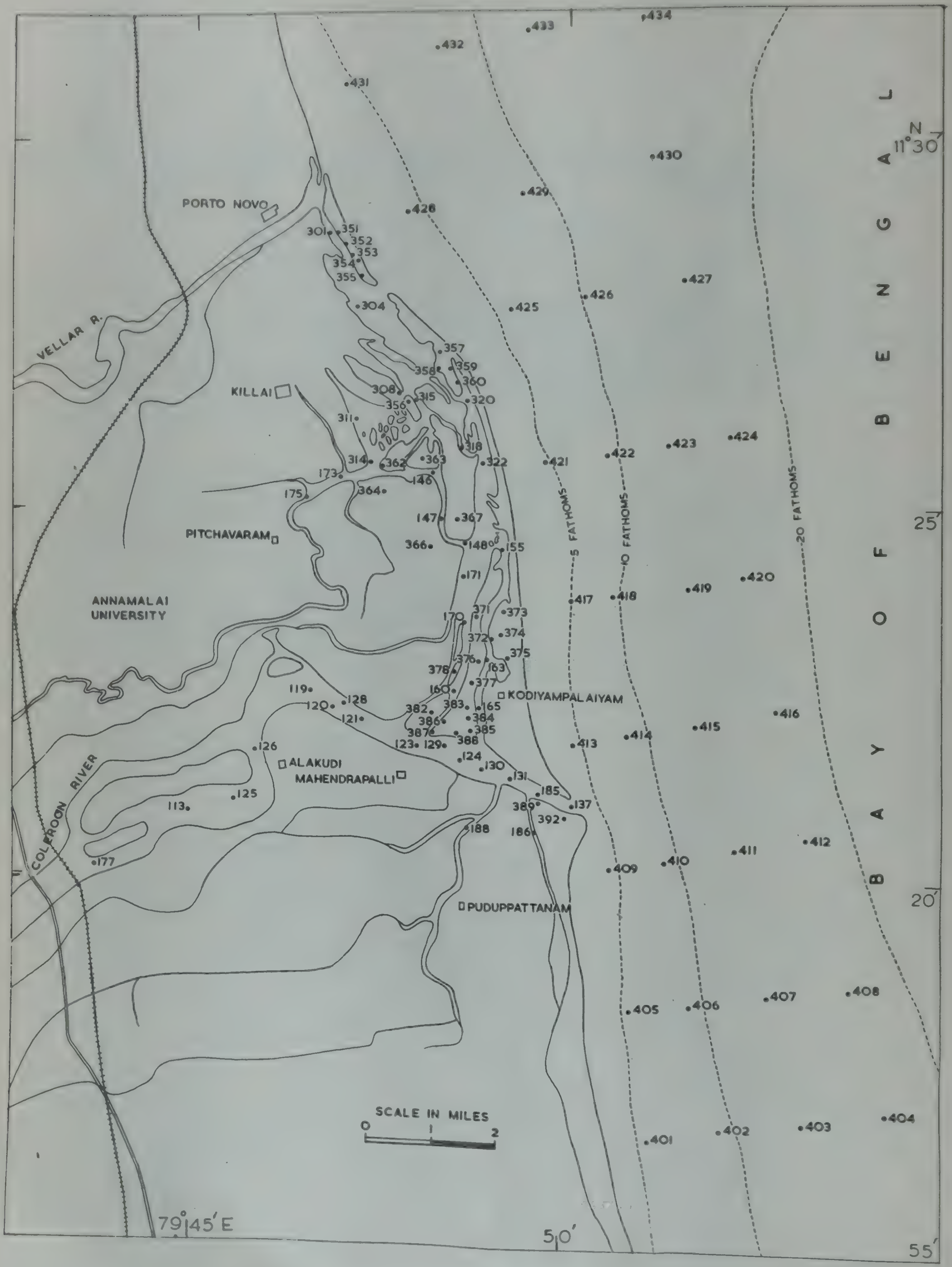
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Fig. 2—Sampling locations in deltaic and marine environment

Table 1—Percentages of Phosphorus, Iron and Calcium in the Clay Fraction of Different Sediments

Sample No.	Phosphorus	Total iron	Calcium
	River channel		
197	0.225	7.20	—
195	0.260	6.45	—
193	0.187	6.90	—
191	0.243	7.45	—
189	0.213	6.35	—
136	0.117	7.80	—
140	0.190	6.60	—
144	0.218	6.80	—
4	0.140	8.80	—
8	0.170	7.00	—
12	0.210	8.10	—
14	0.160	8.60	—
18	0.103	8.20	—
22	0.185	8.30	—
24	0.136	7.50	—
26	0.107	8.15	—
28	0.100	7.65	—
34	0.136	8.90	—
40	0.160	8.30	—
44	0.119	7.60	—
45	0.095	7.10	0.750
50	0.148	7.90	—
53	0.181	9.40	—
56	0.160	9.20	—
60	0.214	6.90	—
65	0.156	8.00	—
66	0.123	8.90	—
67	0.136	8.90	—
74	0.140	8.15	—
78	0.156	7.60	—
80	0.123	8.30	—
83	0.127	7.60	—
88	0.168	7.50	0.550
90	0.148	8.60	—
93	0.111	7.60	—
96	0.144	10.00	—
101	0.115	8.75	0.400
104	0.123	8.30	—
107	0.107	8.30	—
110	0.132	7.30	—
111	0.127	7.75	—
114	0.123	6.90	—
	Estuary		
177	0.160	7.00	—
113	0.196	6.90	—
125	0.208	6.65	0.325
126	0.223	6.30	—
119	0.163	6.40	0.195
120	0.148	6.65	—
128	0.181	6.65	—
121	0.144	5.90	0.225
123	0.193	7.50	—
129	0.156	6.55	—
124	0.139	6.90	—
130	0.141	6.30	0.250
131	0.145	5.75	—
185	0.163	6.30	—
157	0.220	6.90	—
	Marine		
401	0.215	7.10	0.300
402	0.185	7.30	—
403	0.207	7.00	0.250
404	0.166	7.00	0.370
405	0.211	6.55	0.250
406	0.234	7.25	—
407	0.370	7.25	—
408	0.174	6.40	—
409	0.204	6.90	—
410	0.196	6.20	0.300
411	0.181	6.40	—
412	0.165	6.30	—
413	0.192	6.70	0.500
414	0.279	7.10	—
415	0.340	6.70	—
416	0.156	6.30	0.225
417	0.302	5.75	—
418	0.238	6.90	—
419	0.204	7.10	—
421	0.215	6.70	—
422	0.189	6.65	—
423	0.370	6.05	0.225
424	0.189	6.65	—
425	0.226	7.45	—
426	0.192	6.65	—
428	0.230	6.65	—
429	0.181	6.65	—
430	0.383	5.50	—
431	0.222	5.95	—
432	0.202	6.20	—
433	0.194	5.50	—
434	0.241	6.05	—
	Tidal channel		
301	0.143	5.95	—
304	0.162	5.40	0.225
308	0.207	6.05	0.203
311	0.185	6.20	—
314	0.230	7.45	—
315	0.192	6.08	—
318	0.207	7.00	—
320	0.245	6.70	—
322	0.260	6.40	—
175	0.210	6.20	0.195
173	0.115	6.40	—
146	0.115	5.95	—
147	0.174	6.35	—
148	0.180	6.28	—
171	0.152	7.10	0.200
155	0.156	6.40	—
170	0.144	5.98	—
163	0.136	7.00	0.198
160	0.175	6.00	—
165	0.177	6.66	—
186	0.136	5.90	—
188	0.148	5.75	—

Contd

Table 1—Percentages of Phosphorus, Iron and Calcium in the Clay Fraction of Different Sediments —*Contd*

Sample No.	Phosphorus	Total iron	Calcium
	Mangrove		
351	0.158	6.55	—
352	0.158	6.92	—
353	0.151	7.00	—
355	0.223	7.70	0.198
356	0.162	7.10	—
360	0.223	6.96	—
362	0.090	5.65	—
363	0.245	5.40	0.200
364	0.181	5.95	—
366	0.152	7.30	—
367	0.260	6.90	—
371	0.100	5.98	—
372	0.103	5.95	0.190
	Swamps		
354	0.132	6.65	—
357	0.203	7.60	—
358	0.117	7.30	—
359	0.173	6.40	—
373	0.304	6.45	—
374	0.204	6.55	—
375	0.208	5.60	—
376	0.234	7.81	0.195
377	0.136	7.45	—
378	0.132	8.00	—
382	0.226	7.15	—
383	0.230	7.60	—
384	0.200	7.10	—
385	0.241	7.00	—
386	0.181	7.45	—
387	0.211	8.10	—
388	0.123	5.50	—
389	0.111	6.30	0.193
391	0.238	7.60	—

particularly phytoplankton[11,12] in August to October and high zooplankton population[13] in March/April, the later coinciding with the upwelling period off Cauvery Delta[14].

Phosphorus is a biophile element forming an important constituent of cytoplasm of all organisms[15] and can be concentrated by phytoplankton[16]. In the present study the covariance between organic matter and phosphorus in different environments (Fig. 3) leads to the inference that most of the phosphorus in the Cauvery deltaic sediments is tied up in the biogenous components.

In the fresh water river channel (Fig. 3) phosphorus shows a slight positive correlation with organic matter indicating little precipitation of phosphorus as organic phosphate. This covariation can be further explained from the trends of phosphorus and organic matter downstream. However, the phosphorus content except for a slight decrease in upstream (48 km) shows no much variation further downstream. Thus from the downstream trend (Fig. 4) and from Fig. 3 it can be presumed that the geochemical affinity between these 2 constituents is not stronger.

Phosphorus may also be fixed with iron as ferricphosphate in the form of chemogenous compounds. In the swampy environment the covariance exhibited by the phosphorus and iron (Fig. 3) indicates a geochemical relationship between them. Most probably iron and phosphorus are coprecipitated in the form of ferricphosphate. According to Goldschmidt[17] the "oxidation and reduction of iron compounds couple the geochemistry of iron with that of the other elements. Oxidation of Fe^{2+} to Fe^{3+}

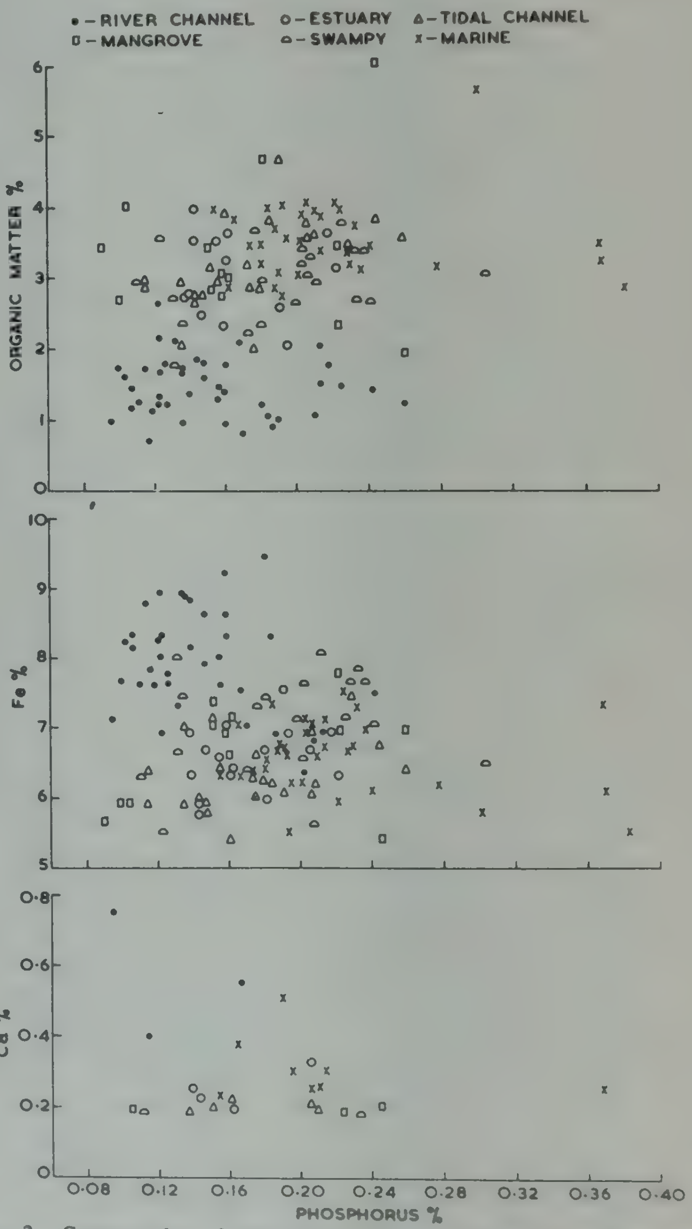

Fig. 3—Scatter plot of phosphorus versus calcium, total iron and organic matter

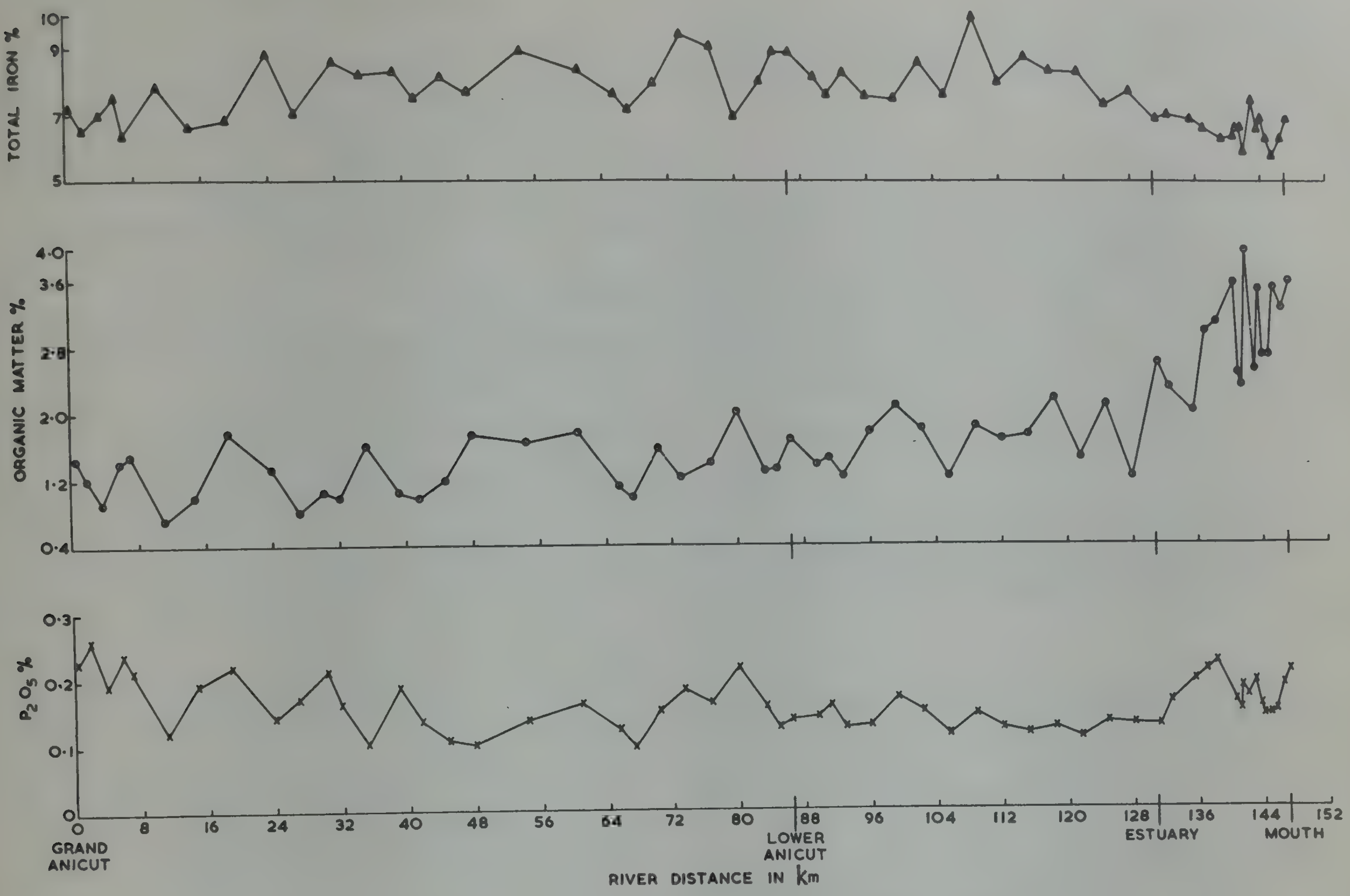

Fig. 4—Down stream variation of phosphorus, organic matter and total iron

favours the fixation of phosphorus as very insoluble basic or normal ferricphosphate or perhaps rather ferricphosphoric acid". Hirst[18] has pointed out the formation of ferricphosphate by the primary adsorption of negatively charged phosphate PO_4^{3-} ions by positively charged ferrichydroxide solutions. Absorption of phosphate anions by ferrichydroxide solutions is generally favoured on account of the adsorbate forming a compound of low solubility with the absorbent[19]. Vinogradov[20] has referred to the selective occlusion of PO_4^{3-} ion by ferrichydroxide. Bapat[21] has experimentally demonstrated the special role of iron in phosphate absorption in soils. In view of the above it is probable that the formation of ferricphosphate in the swampy environment has taken place due to the co-precipitation of ferrichydroxide solutions and phosphate anions. The same explanation can be extended to other environments where there is a good relationship between phosphorus and iron.

However, very little covariance is observed from Fig. 3 for the fresh water river channel which indicates that the precipitation of ferricphosphate is less when compared to other environments. The percentage of iron increases to a distance of 112 km from Grand Anicut and decreases slightly there after (Fig. 4).

But in the marine environment, an antipathetic relationship is observed between phosphorus and iron (Fig. 3). This may be due to the decreasing oxidative precipitation of iron and the corresponding fixation of phosphorus with iron as ferricphosphate may be much less. In the absence of ferricphosphate, phosphorus would have mainly fixed as organic phosphate in the marine environment in view of the high organic life[11-13].

In the marine, estuarine and river environments there is a covariance between phosphorus and calcium (Fig. 3). Probably part of the phosphorus might have been precipitated as calcium phosphate. However, in other environments there is not such covariance.

Finally, a comparative study of phosphorus in the Cauvery River with other rivers in the east coast of India reveals that the phosphorus contribution of this river to the Bay of Bengal is (av. 0.152%) significantly high[22-24].

Probably the phosphorus might have been derived from the carbonatite and other deposits that are present in the drainage basin of the Cauvery River. Srinivasan[25] has reported that the carbonatites of Hogenakal are rich in rounded and ellipsoidal apatite grains. Another source may be the createaceous formations of Trichnopoly in which rich phosphatic nodules are present particularly in the Uttatur stage[26].

Marudaiyer and other small streams that drain the cretaceous formations join the Coleroon River at various places and bring significant amount of phosphorus.

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Organic Matter in the Modern Deltaic Sediments of the Cauvery River

P SERALATHAN & A SEETARAMASWAMY
Department of Geology, Andhra University, Waltair 530 003

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Organic matter in different environments of Cauvery Delta both in bulk samples and clay fractions has been estimated. Clay fractions of the marine sediments have the highest organic matter (av. 3.51 %) and the river clays have the lowest (av. 1.44 %). Organic matter in bulk samples ranges from 0.14 to 3.68 % and in clay fractions from 0.7 to 5.97 %. Organic matter in the bulk sediments generally follows the distribution pattern of the sediments, finer the texture greater the organic matter, and the highest average percentage of organic matter 2.5 is observed in the mangrove sediments where the sediments are muddy and sandy mud in nature. Planktonic bloom and dense vegetation also favour the richness of organic matter in most of the environments.

Information on the geochemistry and grain size of Cauvery Delta sediments is scanty[1-5] and no information is available regarding the organic content of the deltaic sediments as a whole. A detailed study, therefore, has been made on the distribution of organic matter in the river channel, estuary, tidal channels, mangrove, swampy and marine environments of the Cauvery Delta.

Materials and Methods

Description of study area, location of stations and methods of sampling were same as given earlier[6]. Pipette analysis was carried out from a known weight of the air dried sediment sample according to the procedure given by Krumbein and Pettijohn[7]. From the data cumulative frequency curves were drawn and the median diameters computed. Sand, silt and clay ratios were calculated and textural characteristics of sediments recorded[8]. Organic carbon was determined in bulk sample and clay fraction by the direct method[9] and the organic matter obtained by multiplying the organic carbon value by a factor of 1.724.

Results and Discussion

Percentages of organic matter in bulk sample and in clay fraction along with the phi median are given in Table 1. Organic matter in the bulk sample and clay fraction varies considerably from one environment to the other. Some of the salient features regarding organic matter distribution are as follows: (1) River channel sediments have lowest average content of organic matter both in bulk (av. 0.66 %) as well as in clay fraction (av. 1.44 %). (2) On an average highest organic matter (av. 2.5 %) is observed in the bulk samples of the mangrove sediments compared to 2.45, 2.02, 1.92, 1.05 and 0.66 % respectively in marine, swampy, tidal channel, estuary and river channel. (3) Among different environments the clay fraction of the marine sediments exhibits highest average organic matter (3.51 %). (4) Organic matter content in general, follows the sediment distribution pattern. Distribution of organic matter shows a strong negative correlation with grain size. (5) The average organic matter content is strikingly high compared to the other major deltaic sediments of the east coast of India[23-25].

In all the environments the fine grained sediments are generally rich in organic matter. To confirm this, phi median diameter of the sediments (except river sediments which are predominantly sands) was plotted against the bulk organic matter. Organic matter increases as the phi median increases. Such a positive correlation (Fig. 1) between organic matter and phi median (negative correlation with grain size) is almost universally observed in non carbonate, fine grained sediments in marine and lacustrine environments because of absorption of organic matter by clays[10-16]. The main cause for the increase of organic matter in fine particles is the similarity in the settling velocity of both organic constituents and fine particles[17]. Link[18] has observed an average increase of 0.2 % organic carbon for each phi unit increase in mean size.

In the present study except for 1 or 2 exceptional abnormalities, relatively higher organic matter is observed in the higher phi median size. Particularly, the mangrove sediments contain higher percentage of muddy and sandy mud with high median diameter and correspondingly high percentages of organic matter. In the marine environment, particularly in the 2 northern most traverses having high percentage of sand the phi median size ranges from 3.63 to 3.95 and

Table 1—Phi Median and Percentages of Organic Matter Both in Bulk and Clay Fraction

Sample No.	Texture	Phi median	Organic	
			Bulk	Clay
		River channel		
197	A	—	0.44	1.45
195	A	—	—	1.20
193	A	—	0.36	0.90
191	A	—	—	1.40
189	A	—	0.55	1.50
136	A	—	0.18	0.70
140	A	—	0.24	0.98
144	A	—	—	1.75
4	A	—	0.68	1.33
8	A	—	—	0.80
12	A	—	0.46	1.05
14	A	—	—	0.95
18	A	—	0.57	1.60
22	A	—	—	1.03
24	A	—	0.38	0.95
26	A	—	0.54	1.18
28	A	—	—	1.74
34	A	—	0.58	1.64
40	A	—	1.02	1.76
44	A	—	0.65	1.12
45	A	—	0.41	0.97
50	A	—	0.84	1.57
53	A	—	—	1.20
56	A	—	0.80	1.38
60	A	—	—	2.00
65	A	—	0.55	1.28
66	A	—	—	1.30
67	A	—	0.74	1.67
74	A	—	—	1.36
78	A	—	0.63	1.45
80	A	—	0.7	1.21
83	A	—	—	1.76
88	A	—	0.76	2.07
90	A	—	1.70	1.79
93	A	—	0.68	1.21
96	A	—	1.06	1.83
98	A	—	0.90	1.67
101	A	—	0.92	1.72
104	A	—	1.04	2.17
107	A	—	0.83	1.43
110	A	—	0.96	2.10
111	A	—	0.48	1.21
114	A	—	1.11	2.61
		Estuary		
177	B	2.35	0.28	2.30
113	B	3.60	0.37	2.01
125	B	2.26	0.31	3.00
126	B	2.32	0.14	3.10
119	C	5.23	3.15	3.59
120	D	8.63	2.03	2.47
128	C	4.40	0.91	2.36
121	E	2.84	0.74	3.95
123	B	3.60	0.72	3.53
129	C	5.50	1.86	3.50
124	C	5.08	1.00	2.71
130	B	3.58	0.91	2.71
131	B	3.76	0.66	3.50
185	B	2.80	0.31	3.26
157	C	6.55	2.29	3.59
		Marine		
401	C	7.85	2.38	3.84
402	F	6.65	2.72	3.93
403	C	6.80	3.67	4.02
404	C	7.80	1.69	3.76
405	E	6.37	2.72	3.93
406	C	6.40	3.07	3.67
407	C	7.20	2.81	3.15
408	C	7.60	3.12	3.41
409	B	3.63	1.60	3.84
410	B	5.68	3.07	3.50
411	C	7.50	3.24	3.41
412	C	7.50	2.70	2.81
413	E	3.63	1.34	3.07
414	F	4.95	2.38	3.07
415	C	6.64	3.02	3.33
416	C	6.85	3.67	3.93
417	E	3.25	1.43	5.57
418	F	6.50	2.48	3.07
419	F	5.66	3.00	3.50
420	—	—	2.50	—
421	E	6.00	2.73	3.33
422	C	6.80	2.38	2.81
423	C	5.30	2.72	3.41
424	B	5.55	2.21	3.67
425	E	6.20	2.29	3.93
426	H	8.44	1.28	2.72
427	—	—	2.40	—
428	E	3.88	1.81	3.17
429	E	3.85	1.81	3.17
430	E	3.95	2.60	2.81
431	E	3.63	2.64	4.00
432	E	3.95	1.36	3.00
433	E	3.90	2.09	4.00
434	E	3.95	2.45	3.36
		Tidal channel		
301	C	7.84	2.38	2.64
304	B	2.90	1.09	3.90
308	F	4.22	3.05	3.59
311	F	5.21	2.81	3.81
314	E	2.62	0.83	3.48
315	B	2.83	2.12	4.60
318	F	5.66	3.61	3.72
320	C	6.30	3.31	3.81
322	B	4.00	0.66	3.53
175	C	6.45	2.72	3.53
173	—	—	2.64	2.72
145	F	4.43	1.00	2.70
146	F	4.76	1.09	2.90
147	D	8.90	2.31	3.17
148	B	3,90	0.74	2.80
155	E	4.16	1.00	2.90
171	C	4.90	1.74	3.16
170	C	5.76	2.03	2.72
163	—	—	1.24	2.09
160	F	4.56	1.17	2.84
165	F	5.23	1.78	2.00
186	D	6.87	2.10	2.90
188	D	7.15	2.64	2.72

Contd

Table 1—Phi Median and Percentages of Organic Matter Both in Bulk and Clay Fraction —*Contd*

Sample No.	Texture	Phi median	Organic		Sample No.	Texture	Phi median	Organic	
			Bulk	Clay				Bulk	Clay
		Mangrove					Swampy		
351	C	7.22	1.91	2.72	358	E	2.94	1.09	3.62
352	C	6.20	2.36	2.90	359	B	3.48	1.36	2.09
353	D	8.41	2.02	2.72	373	H	8.50	2.85	3.00
355	G	9.33	1.17	2.31	374	C	8.00	2.45	3.36
356	D	9.60	2.40	2.95	375	C	6.40	2.17	3.26
360	C	6.00	2.72	3.36	376	D	7.93	2.21	2.65
362	D	7.65	2.38	3.41	377	D	6.90	2.12	2.31
363	D	8.43	3.50	5.97	378	D	6.04	1.70	1.74
364	D	8.43	3.50	5.97	382	F	4.70	1.19	3.72
366	D	7.90	3.20	3.41	383	C	7.04	3.18	3.36
367	G	9.50	1.78	1.98	384	C	5.20	2.09	2.64
371	C	4.83	2.55	2.62	385	C	4.94	1.36	2.64
372	D	6.60	2.81	4.00	386	D	5.80	2.81	2.90
					387	C	6.40	2.17	2.90
		Swampy			388	B	3.92	0.85	3.59
354	C	6.14	1.91	2.72	389	C	5.00	2.03	2.95
357	E	6.44	1.91	3.17	392	C	9.06	2.90	3.36

Texture: A=sand, B=silty sand, C=sandy mud, D=mud, E=muddy sand, F=sandy silt, G=clay, H=sandy clay

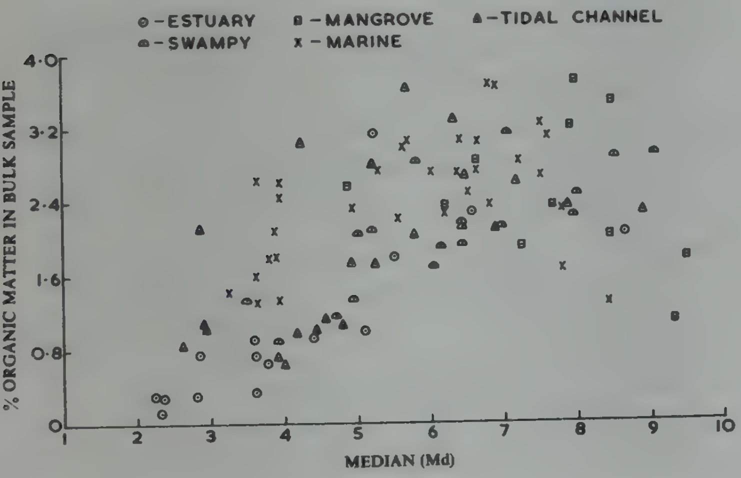

Fig. 1—Relationship between organic matter and phi median in bulk sediment samples from different environments

the organic content in the bulk sediments is slightly less. In the remaining part, the phi median and the organic matter are relatively high. Similarly the swampy, tidal channel and estuarine sediments show positive relationship with phi median size. In the river, the sediments are mainly sands and the size decreases down stream and the organic matter increases progressively.

In the mangrove, inspite of its muddy and sandy mud with higher percentages of silt and clay, the clay fraction does not have the average higher percentages of organic matter. Instead the marine clays have higher percentages. It is believed that the high percentages in the marine environment are mainly due to its hydrobiological conditions.

Good amount of organic matter is supplied by the river in the form of suspended vegetal matter. Besides, large volume of organic debris drains from the overlying water column. The plankton in this marine environments is higher compared to other environments of this area, and this planktonic bloom can be observed in abundance throughout the year[1-3]. According to Sverdrup *et al.*[19], "an abundant supply of organic matter in the column of water, a relatively rapid rate of accumulation of fine grained inorganic matter and low oxygen content of the waters immediately above the bottom sediments would favour high organic matter in the bottom sediments". The planktonic impact on the content of organic matter is evidenced from the foregoing statement. Dissolved oxygen of the marine zone is also lower than the other environments (3.98 ml oxygen/litre)[3]. Besides the low dissolved oxygen, the temperature is also comparatively low in this environment; temperature is also one of the factors that determines organic matter content in the sediments[20,21]. When the dissolved oxygen and temperature are low, oxidation of organic matter will not be much.

Clay fraction of the mangrove sediments shows an average of 3.3% organic matter. The mangrove is highly colonized and the substratum is predominantly muddy and sandy mud and the area is periodically inundated by tidal waves and hence the possibility of supply of considerable amounts of organic matter and its preservation. Sverdrup *et al.*[19] have stated that in shallow water, particularly in isolated environments, attached aquatic plants are important source of organic matter. In addition to the constant supply of organic matter to the substratum, conditions toxic to bacteria causing decomposition of vegetation are prevalent ensuring a high percentage of preservation. Further in the constant moisture caused by the tightly knit tree canopy, oxidation is extremely slow providing additional opportunity for preservation. The fineness of the sediments with low permeability permits poor supply of free oxygen into the interstitial layers of the sediments completely preventing oxidation. In oxygen deficient and non-turbulant conditions a little decomposition of organic matter is favoured[17]. The average organic matter in the swampy environment is 2.95%. This is because of higher oxidation in some of the sample locations.

The tidal channel and the estuary are believed to be subjected to the greatest aeration (next to the river channel) as a result of turbulant action of semidiurnal tides. Even then the results show that the tidal channel and the estuarine sediments have relatively higher amount of organic matter (av. 3.16 and 2.97% respectively). It may be partly due to the fact that these 2 environments are constantly receiving clay sized organic matter from the mangrove, swamps and the river.

The fairly rich amount of organic matter may also be due to the marine conditions observed in these environments. Krishnamurty and Santhanam[22] have reported a fairly rich amount of tintinnids (zooplankton) in the backwaters. They have stated that the backwaters are subjected to marine influences associated with weak upwelling. The plankton values are significantly high in the tidal channels[1-3] and this planktonic bloom adds much organic matter to the bottom sediments of the tidal channels. Eventhough no data are available for the Coleroon estuary regarding the organic productivity, the same conditions may be prevailing in this transitional environment.

Of all the environments the river channel has the greatest turbulance and hence the greatest aeration also. The average organic matter content in the river channel is 1.44%. Perhaps to some extent this is due to the fact that large volumes of suspended organic matter which are supplied from the upstream are continuously drained out to the estuary and then to the sea along with the swift out flow of the river water. Thus the river channel sediments are depleted of a large potential source of organic matter. The other cause may be the relatively coarse texture of the channel sediments; the coarseness increases towards upstream and conversely the organic matter in the sediment decreases.

The average organic matter of clay fraction in Cauvery Delta sediments compared with those of other deltas along the east coast of India[23-25] is strikingly high.

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Hydrographic Features & Water Quality of Cochin Backwaters in Relation to Industrial Pollution

K SARALA DEVI, P VENUGOPAL, K N REMANI, S LALITHA & R V UNNITHAN
National Institute of Oceanography, Regional Centre, Cochin 682018

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Impact of industrial effluents on quality of receiving waters as assessed by COD, suspended solids, and some hydrographic features has been studied over an year at 4 stations in Cochin backwaters. The effect of effluents is considerable in the vicinity of the main discharge site (st 2) in nonmonsoon months. The monsoonal floods provide adequate dilution and mask the effects. No serious oxygen depletion is noticed at any of the stations. An attempt has been made to correlate the relative abundance of benthic fauna at the stations with the water characteristics like ammonia content and organic matter.

Pollution studies on Cochin backwaters have been initiated recently[1]. Impact of organic pollution on the hydrography of the estuary around Willingdon Island has been reported[2]. Incidence of fish mortality from industrial pollution in the upper reaches of the backwaters is also reported[3,4]. The effluents discharged into the backwater system from various industrial establishments, located in Eloor (Udyogamandal), constitute some of the major pollutants in the estuary. The industrial belt extends to nearly 5 km from Varapuzha to Alwaye along the upper reaches of the backwaters. A study has been undertaken during 1976-77 to understand the effect of industrial pollution in the estuarine environment. Results of the study are reported in this paper.

Materials and Methods

Monthly samples at fixed locations were collected from 4 stations (Fig. 1), viz. Kalamassery (st 1), Udyogamandal (st 2), Elamakkara (st 3) and Barmouth (st 4).

Water samples were collected from the surface using a clean plastic bucket. Meyer-type sampler was used for bottom sampling. Bottom sediments were collected using a van Veen grab. Chlorinity was estimated by Mohr-Knudsen method[5], dissolved oxygen by Winkler method[6] and chemical oxygen demand (COD) by refluxing the sample with potassium dichromate[7]. Chloride corrections were made[8] by multiplying the corresponding chloride values for salinity by a factor of 0.225. This factor was arrived at by estimating chloride interference for a series of sodium chloride solutions with known chloride contents ranging from 710 to 28400 mg/litre. Suspended solids were determined by filtering the water sample through a Millipore filter (pore size 0.45 μm) and drying the residue to constant weight at 80-90°C.

Effluent samples collected from the discharge points were also analysed for COD by oxidation with permanganate[9]. Alkalinity was estimated by adding

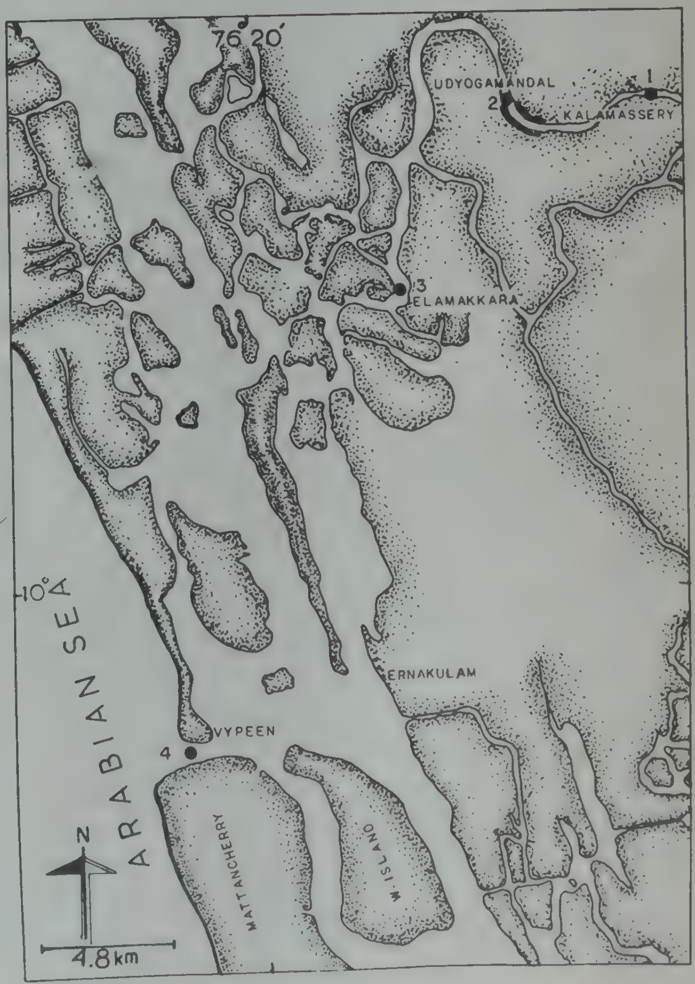

Fig. 1—Location of observation stations in Cochin backwaters

excess H_2SO_4 and titrating the excess acid[7]. Ammonia was determined colorimetrically by indophenol blue method[10]. A seeded dilution method[7] was used in the estimation of BOD_5.

Temperature and *p*H for all water samples were noted at the time of collection. Qualitative observations on benthic fauna were also made from the grab samples.

Results and Discussion

Variations in different parameters during the period of observation are shown in Fig. 2. Monsoonal floods influenced the water quality and hydrographic features at all stations considerably. For the presentation of results the year is divided into 3 seasons: premonsoon (January-May), monsoon (June-October) and postmonsoon (November-December).

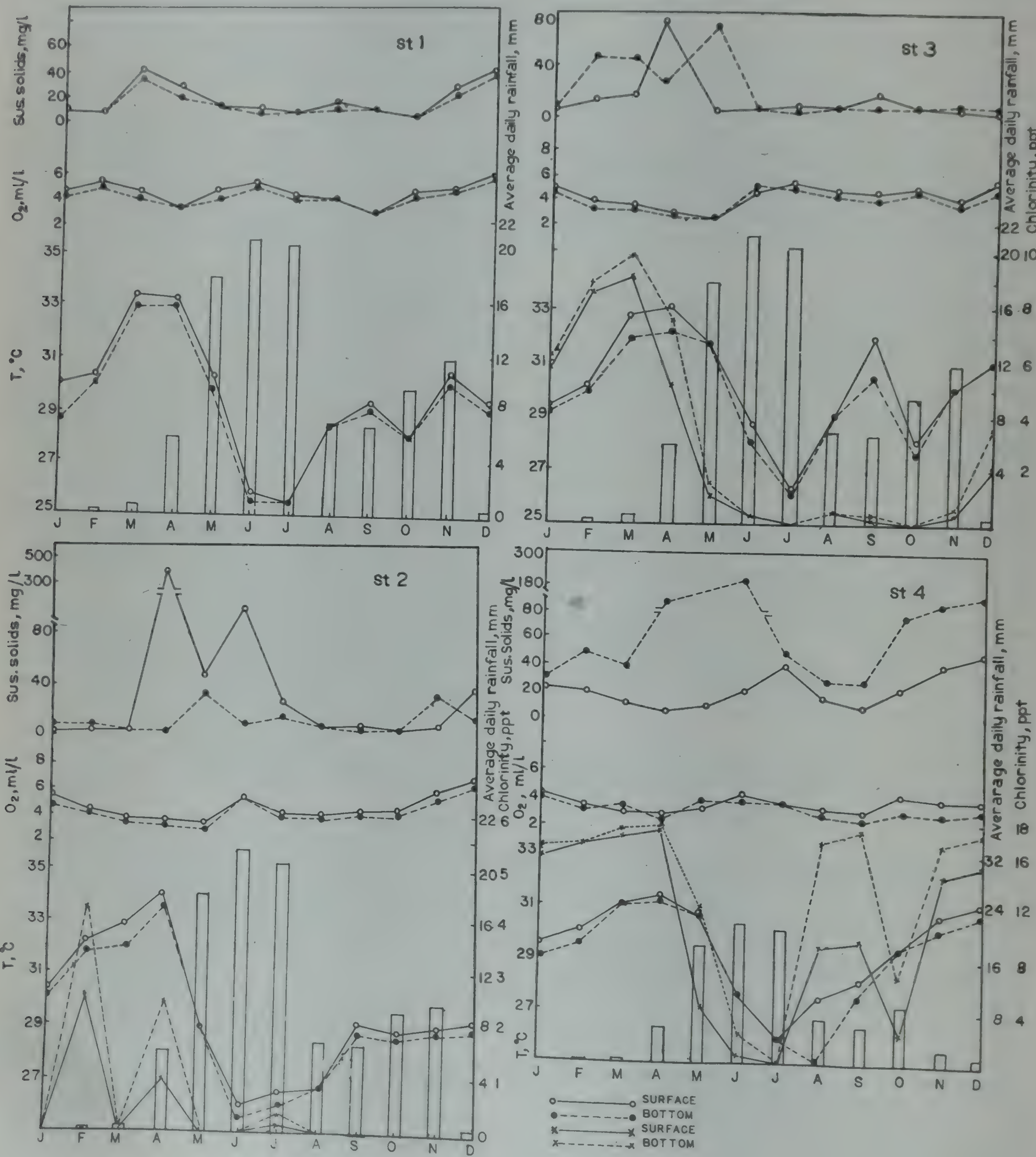

Fig. 2—Temperature, chlorinity, oxygen, suspended solids and rainfall at different stations

Temperature—Annual ranges in temperature were 25.5-33.2, 25.5-34.1, 26.3-33 and 26-31.5 at stations 1 to 4 respectively. St 2 in general showed higher temperature except during monsoon when the river was in spate. The higher ranges in temperature at sts 1-3 can be attributed partly to their shallow nature and absence of strong tidal influence which facilitates water exchange and nullifies localised thermal excursions.

Chlorinity—Sts 1 and 2 had fresh water regime round the year. St 2, however, had higher levels of chlorinity. This station also experienced sporadic increases in chlorinity during the premonsoon season (Fig. 2), presumably due to the release of chlorides through effluents. Analytical data of Jayapalan *et al.*[3] also show wide variations in chloride content during the period of observation (1968-71). They have also reported considerable fluctuations in the chloride content of the effluents. Sts 3 and 4 were subject to more pronounced seasonal variations in chlorinity. The variations at st 3 were from ~ 0-9.2 and at st 4 from almost fresh water to marine conditions. Chlorinity at all stations, like temperature showed inverse relationship with rainfall (Fig. 2).

*p*H—*p*H values ranged from 6-7, 5.5-8, 6-7.5 and 6.5-7.5 respectively at sts 1 to 4. St 2 showed erratic fluctuations during the nonmonsoon months probably due to localised influence of effluents.

Dissolved oxygen—Dissolved oxygen values were higher during the monsoon at all stations, and were low during the premonsoon months. Surface values in general remained higher (Fig. 2). There was no indication of an oxygen gradient, except at st 4 during the monsoon months. This gradient which disappeared with the re-establishment of marine conditions has been reported previously[11]. The absence of a gradient at sts 1-3 may be due to their shallow nature. The annual ranges in values for oxygen were 3-6, 3-5.8, 3-5.5 and 2-4.2 ml/litre respectively for sts 1 to 4. There was no indication of any serious depletion of oxygen at any of the stations.

Suspended solids—Patterns of distribution of suspended solids were different in the 4 stations (Fig. 2). St 1 had lower quantities of suspended solids (4-40 mg/litre) as compared to sts 2 to 4 (4-408, 3-75 and 4-260 mg/litre for sts 2 to 4 respectively). St 1 had higher values in pre and post monsoons, which came down during the monsoon. St 2 showed wide fluctuations in suspended load, the surface values being generally higher and subject to wider variations (Fig. 2). St 3 had higher values during premonsoon months which came down in the monsoon months. Higher values in premonsoon may partly be due to the local disturbances caused by a small time fishery of the estuarine clam *Villorita cyprinoides*. Sts 1, 2 and 3 had comparable values during the monsoon season indicating the influence of high river discharge. However, st 2 showed a high value in June presumably derived from the effluents. At st 4 the suspended solids showed higher values, with very high values during monsoon (Fig. 2). Gopinathan and Qasim[12] have attributed the higher level of suspended solids to resuspension of sediment material by fresh water runoff and strong tidal action.

Chemical oxygen demand—Table 1 gives the average values and ranges of COD for the 4 stations. In calculating the average values and ranges, figures too close to the calculated chloride-interference have been discarded as unreliable. COD values were low and quite comparable at sts 1 to 3 during monsoon. Values at st 4 were higher compared to the other stations. The higher average values at st 4 were due to high values (1216 mg/litre at surface and 2237 mg/litre at bottom) in June. The values for the rest of the monsoon season were considerably lower. High values in June may be due to the added load of organic matter brought down with the land drainage following the first monsoonal showers. Premonsoon values were higher at all stations indicating a build up of organic load. St 2 had fairly high values during this season, but showed considerable range of variations (Table 1) indicating fluctuating COD load. The oxygen assets of the

Table 1—Chemical Oxygen Demand (mg/litre) of Water

Station	Depth (m)		Premonsoon		Monsoon		Postmonsoon	
			Range	Average	Range	Average	Range	Average
1	2-2.5	S	20-65	35	5-15	12	28-40	34
		B	15-62	37	8-15	13	5-36	21
2	2-2.5	S	93-322	200	15-25	20	16-27	23
		B	25-307	203	10-22	18	20-29	25
3	2-2.5	S	78-192	110	27-70	30	33-43	38
		B	15-1043	367	30-60	30	15-107	61
4	6-7	S	197-3797	1882	184-1217	653	300-1020	560
		B	312-2795	1706	192-2237	447	380-970	675

S = surface and B = bottom

Table 2—Characteristics of Effluents on Entering the River (February 1977)

Source of effluent	Temp. (°C)	Chlorinity (ppm)	*p*H	Diss. oxygen (ml/1)	Alkalinity (mg $CaCO_3$/1)	Susp. solids (mg/l)	Permanganate consumed (mg/l)	COD (dichromate; mg/l)	BOD_5 (mg/1)	Ammonia (ppm)	Colour of effluents
Periyar Chem.	33.9	200	8	1.8	117	264	51.3	4400	51.3	0.12	Orange
Catalysts & Chem. India Ltd	43.9	310	6	1.4	16.4	184	7.67	20	14.3	2.76	Brown
Cominco Binani Zinc Smelters (1)	35.5	300	2	<0.05	195.8	8	11.93	50	1.3	0.15	Colourless
Bleach ,, (2)	32.2	50	2	4.5	157.7	16	6.67	10	—	1.1	do
Indian Rare Earths Ltd	36	50	6	4.2	10.8	15	12.67	20	6.3	1.86	do
FACT	30.2	50	6	4.4	16.3	12.5	14	30	5.3	3	Light grey
TCC	31	150	7	4.3	16.4	50	14.67	190	—	0.18	Colourless
Water Sample Upstream	29.5	50	6.5	6.9	18	8	5.3	20	9	0.03	do

receiving waters at this station, however, did not show any serious depletion (Fig. 2). St 4 had consistently higher values throughout the period of observation, probably due to domestic sewage and other particulate wastes discharged into the harbour area. Previous studies[1,2] have also shown appreciable degree of organic pollution in the harbour area.

It is to be stressed that the COD by dichromate reflux method has the disadvantage of high background noice due to chloride interference in saline waters. The oxidisability of chlorides in dissimilar systems containing organic and non-organic matter is reported to be different[13]. Hence, the present data may be treated as an index of the order of magnitude of organic load.

Some characteristics of the effluents discharged at st 2 are listed in Table 2. They all had higher temperature than ambient temperature, varying *p*H and alkalinity, and ranged from well oxygenated to poorly oxygenated (<0.05 ml/litre). The oxygen demand was generally low except in one instance where COD was 4400 mg/litre (Table 2). This effluent came from an organic chemical factory. Suspended solids were generally high and foam and oil slicks could be noticed on many occasions at the discharge area. Ammonia levels varied from 0.1-3 ppm, which in 2 instances surpassed the acceptable value[14] of 2.5 ppm. Jayapalan *et al.*[3] have also reported high ammonia values for some effluents from the same area. BOD_5 values were quite variable probably due to the relative toxic effects on the bacterial flora. Only one effluent had appreciable BOD_5 value (Table 2), and 2 showed oxygen depletion lesser than the seed sample. Values for BOD_5 were in most cases well above those for natural waters, though the highest value recorded was only 1/6-1/10th of that for domestic sewage[15].

Data on the oxygen demand characteristics of the effluents and different stations do not reveal appreciable organic loads at sts 1 and 2 and the effluents, except in one case (Tables 1 and 2). Although st 2 experienced sporadic high oxygen demand during premonsoon it failed to show significant influence on the oxygen assets of the station. St 4, however, showed consistently higher oxygen demand (Table 2). Comparison of these 2 areas and analytical data on the effluents suggest that the pollution load at st 2 is not principally organic and that the organic load does not seriously deplete the oxygen.

Observations on the qualitative aspects of benthic life showed that sts 1, 3 and 4 supported benthic life. St 1 had 2 species of mussels, *Lamelliden marginalis* and *Batissa* sp. throughout the year. The estuarine clam *Villorita cyprinoides* of different size groups was present at st 3 at all times, indicating a thriving population. St 3 also supports a small time fishery. In the higher saline periods (premonsoon) gammarid amphipods were common at this station. St 4 had a fairly diverse benthic life as reported[16]. Higher organic load at this station failed to show any deleterious effects on aquatic life.

Examination of the discharge area from a biological point of view would indicate that the stresses at st 2 are varied and intermittent (Tables 1 and 2). The present investigation and available information[3,4], show the presence of high ammonia, a potent toxin, in the effluents and at times in the water. Higher loads of suspended material, higher temperature and variable *p*H along with the occasional high chloride and COD levels especially in the dry months seem to make this environment hazardous. A gradient of stress which diminishes away from st 2 towards both upstream and downstream is apparent.

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Faunal Composition in Polluted Nearshore Environment

P GOPALA MENON, M MADHUPRATAP*, P HARIDAS, P VENUGOPAL & T S S RAO*
National Institute of Oceanography, Regional Centre, Cochin 682018

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Faunal density and distribution in a nearshore environment at Trivandrum, into which effluent from a titanium dioxide factory is discharged has been studied. The effluent chiefly contains sulphuric acid, ferrous salts and titanium dioxide. Analysis of samples from the affected and unaffected areas shows a decrease of intertidal and benthic fauna in the polluted areas. Gross ecological variations appear to have not taken place and the marginal changes that occur in the environment can be considerably reduced by controlling the pollution.

Awareness of the role of ecological monitoring in pollution studies has been growing in the recent past. The Travancore Titanium Products Ltd (TTP), situated at Kochuveli, Trivandrum (08°30′ N; 76°55′ E), discharges effluents into the beach which go into the coastal waters of the Arabian Sea. Recognizing the hazards of pollution caused by the effluent discharge, the TTP requested the National Institute of Oceanography to survey the area and suggest, if necessary, remedial measures. Some studies on the effects of the effluent on interstitial fauna have been conducted[1,2]. Aspects of pollution caused by the effluent discharge gauged from faunal abundance and distribution form the subject of this study.

Materials and Methods

The effluent discharged (~ 4000 m^3/day), chiefly containing sulphuric acid (~ 3%), ferrous salts (10-40 g/litre) and titanium dioxide, mixes with the sea water and spreads along the coast, northward or southward, depending on the direction and force of the littoral drift. The oxidation of the ferrous salts into ferric salts on mixing imparts a reddish brown colour to the sea water with very poor transparency and this patch extends to a width of 0.3 to 0.5 km (5 to 7 m depth) from the shore. The coastal zone in this area is thickly populated and fishing activities mainly using country crafts, hook and line, shore seins and gill nets are conducted throughout the year.

Studies were conducted from November 1976 to December 1977 to assess the possible harmful effects of the effluent on the biota. Samples were collected at monthly intervals from 3 stations, viz. TTP effluent outfall area, Thumba-Vikram Sarabhai Space Centre which is about 5 km north of TTP and Sankhamugham, located about 5 km south of TTP. Samples were also taken from Kovalam (15 km south) which remains more or less 'clean' throughout the year. Intertidal fauna were collected from high to low tide levels using a metal quadrant (area 10 cm^2, depth 16 cm). Collections were also made from the swash zone. Benthic fauna were collected using a van Veen grab (area 0.048 m^2) along traverses perpendicular to the coastline at these stations at 5, 10 and 20 m depths. Fauna from these were collected by washing the samples through a 0.5 mm screen and preserved in 4% formalin. They were identified, counted and dry weight recorded (shells were removed whenever present). Zooplankton samples were collected from the effluent patch and beyond, along the coast, using the Heron-Tranter (HT) net (mesh size—300 μ) with a flow meter attached and analysed both for quantitative and qualitative data. Direction of the littoral drift was ascertained using Rhodamin B dye as a tracer. Measurements of *p*H, oxygen, salinity and temperature were also made at all the stations.

Results and Discussion

The intertidal fauna consisted of archiannelids, polychaetes, nematods, mysids, harpacticoid copepods, cumaceans, amphipods, decapods, lamellibranchs and gastropods. The effluent outfall area at TTP was virtually devoid of any beach fauna, except on 2 occasions when also the density of population and the biomass were comparatively low (Fig. 1) consisting of a few archiannelids. Benthic organisms encountered off Trivandrum coast consisted of polychaetes, nematods, sipunculids, mysids, tanaidaceans, cumaceans, ostracods, amphipods, decapods, lamellibranchs, gastropods and *Amphioxus*. The substratum consisted of sandy silt or silty sand.

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*Present Address: National Institute of Oceanography, Dona Paula, Goa 403004

From the general distribution pattern of the organisms it was observed that in the intertidal zone, archiannelids formed the dominant component (76.7% of the total annual counts) occurring more or less consistently followed by amphipods (18.1%) and *Emerita* sp. (3.8%). But the latter 2 contributed to the majority of the biomass. *Donax* sp. which was reported to be a dominant component of intertidal fauna from Shertallai and Cochin beaches[3], did not occur at the Trivandrum beaches during the present study. However, during the present observation they were absent at Cochin also but occurred in very large numbers at the Mopla Bay and Payyambalam beaches, Cannanore and West Hill beach at Calicut, Kerala during the premonsoon months. The average biomass at the unaffected area, viz. Kovalam (3.5 g/m^2) is higher than the reported figures from Shertallai (1.5 g/m^2) and Cochin (1.7 g/m^2) beaches. In the surf sand, mysids dominated the counts (44%) followed by archiannelids (28.6%), *Emerita* sp. (22.4%) and amphipods (4.6%). Polychaeta dominated the total counts (34.6%) followed by Amphipods (27.2%), *Amphioxus* (17.1%), Cumacea (14.6%), Nematoda (3%) and Mysidacea (1.6%) in the benthic fauna.

The effluent on mixing with the sea water causes changes in the temperature, *p*H and oxygen content (through oxidation of Fe^{2+} to Fe^{3+}) and thus affects the organisms. Although the temperature of the effluent was high (45-50°C), at the discharge point, its effect on the fauna was less owing to rapid reduction in temperature on mixing with the sea water. The littoral drift showed a northerly direction during most months except in June and July when it became southerly (towards Sankhamugham). During February-April also, when the littoral drift was weak, the effluent was observed to spread both towards Sankhamugham and Thumba regions, with a net flow towards south. The direction of the drift of the effluent was also discernible from the distribution of *p*H in sea water and values of different parameters from representative months are given in Table 1.

Although acute toxic levels were reduced as the effluent mixed with sea water moved away from the outfall area, constant exposure to the suspended precipitate and solids from the effluent present in the sea water, which washes the intertidal zone, resulted in depletion/death of the fauna. A decrease was observed in diversity owing to prolonged sublethal effects such as slow chocking of the respiratory and feeding organs particularly of benthic fauna. Experimental studies on mussels fed with ferric hydroxide flakes along with other food[4] showed that although this did not bring about acute toxicity, caused a decrease in their body weight and high mortality rate. The effect of the effluent was further confirmed in toxicity study experiments conducted in the laboratory[5] on selected benthic organisms and fishes. Concentrations up to 0.6% of the effluent were acute toxic levels (*p*H 4.1, oxygen depletion 70%) causing death of the organisms within 2 to 10 min. Prolonged exposure to the precipitate from neutralised effluent also caused mortality. This effect was apparent from the distribution of organisms at

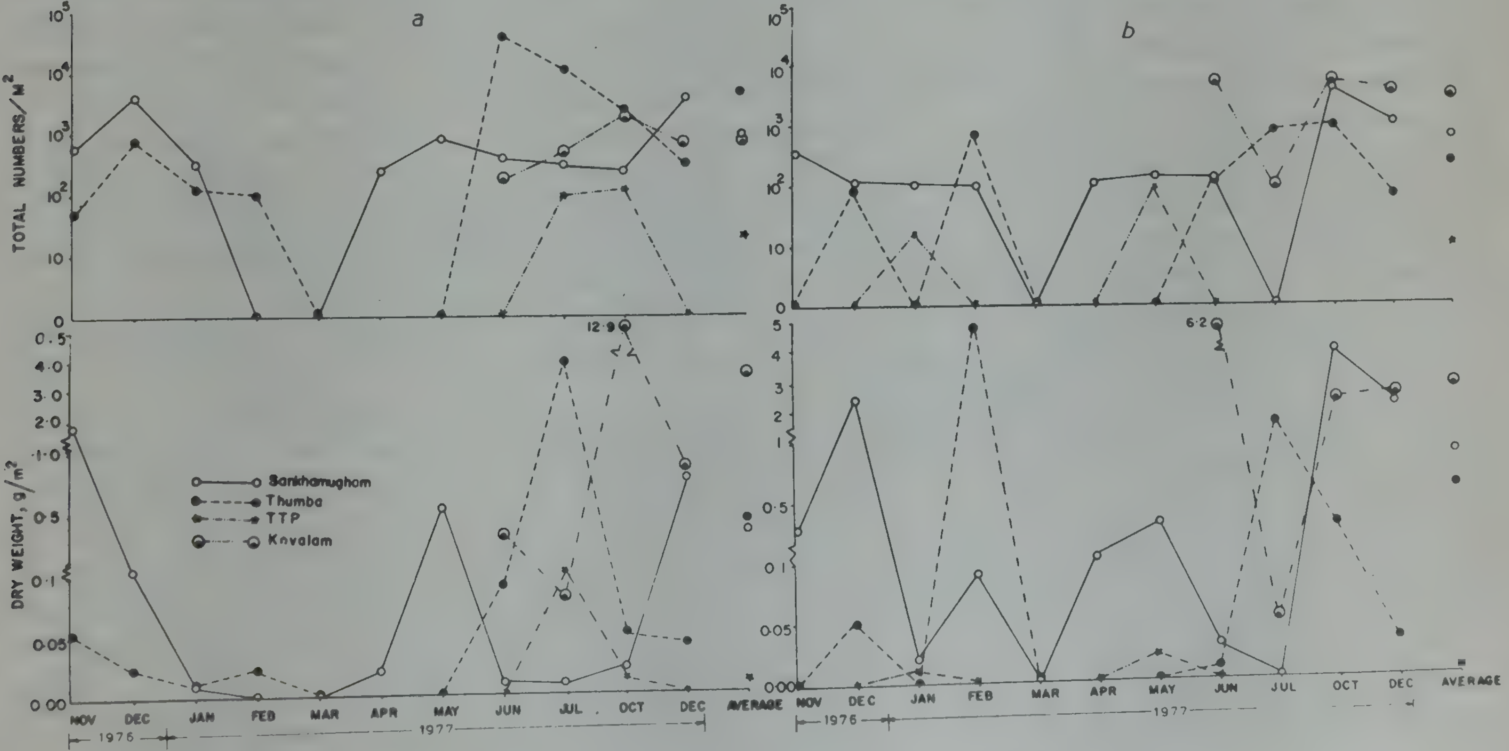

Fig. 1—Distribution of (a) intertidal and (b) wash zone fauna (total numbers and biomass) at different stations

Table 1—Physical and Chemical Parameters of Effluent and Surface Water at the Point of Mixing and at Different Distances from the Effluent Discharge Point in February and December 1977

[December values are in parentheses]

Parameter	Effluent	At mixing point	100 m S	200 m S	2 km S	100 m N	200 m N	2 km N	0.5 km offshore	1 km offshore	2 km offshore
Temperature °C	46.5	28.5 (31)	28.5 (30)	28.4 (30)	27.8 (30)	28 (31.5)	28 (30.5)	28.7 (30.5)	28.5 (30)	28.4 (30.1)	28.5 (29.5)
*p*H	1	2.4 (2)	3.3 (6.9)	5.7 (7.6)	7.8 (7.7)	7.9 (1.8)	7.9 (2.3)	7.8 (7.5)	2.4 (7.6)	8.4 (7.7)	7.9 (7.8)
Total solids mg/litre	850	59 (34.8)	33 (15.8)	— (8)	22 (7.7)	— (—)	10 (48.3)	10 (66.6)	9 (13.3)	9 (13.3)	10 (—)
O_2 mg/litre	—	5.9 (0.7)	7 (5.9)	7 (6.1)	7.7 (6.4)	4 (—)	5 (0.4)	7 (6.3)	8 (4.5)	8 (7.2)	7 (6.3)
Salinity (‰)	—	33.4 (33.2)	33.2 (33.4)	33 (34)	33.4 (33.9)	33.1 (33.2)	33.9 (34)	33.7 (33.9)	34.6 (34)	33.9 (33.9)	33.9 (34.1)

S = South; N = North — = No data

Sankhamugham and Thumba. Sharp decrease in faunal abundance and biomass was observed in February-March and later in June-July at Sankhamugham when the effluent spreads in a southerly direction. Similarly, a recovery of faunal abundance was observed at Thumba consisting chiefly of archiannelids in June-July when this area became free from the effluent. Kovalam, which was an unaffected area, sustained higher numbers of organisms and biomass. Differences in average numbers and biomass of organisms in various habitats and areas highlighting variations between polluted and non-polluted areas are given in Table 2.

Effects of pollution were manifested on the benthic organisms also. At the 5 m depth zone, where the overlying water column was contaminated with effluent precipitate and the substratum covered with sediments from the effluent, the numbers of benthic organisms and biomass were very poor compared with the same depth zone at the unaffected Kovalam area (Fig. 2). This was especially so at the effluent outfall area. Thumba region which was exposed to the effects of the effluent for most part of the year, showed lesser benthic faunal abundance compared to Sankhamugham transect.

A general increase in the abundance of benthic fauna was observed with the increase of depth. At 10 and 20 m, which are unaffected depths, the abundance of fauna was comparable at all stations. The extent of depletion of benthic fauna at various stations due to the effluent could be further assessed from the depthwise increase of faunal abundance towards offshore. The average increase from 5 to 20 m in terms of numbers was 4 times at Sankhamugham, 19.5 times at Thumba and 195 times off TTP; for biomass, it was 18.5, 84 and 270 times respectively. On the other hand at Kovalam, the increase was only 1.4 times for numbers and 5.2 times for biomass.

Table 2—Average Increase in Number and Biomass of Organisms at Various Stations

[Figures are given as times higher than at TTP]

	Sankhamugham	Thumba	Kovalam
		Intertidal organisms	
Numbers	49	268	42
Biomass	31	37	127
		Swash zone organisms	
Numbers	55	29	350
Biomass	273	193	886
		Benthic organisms (at 5 m depth zone)	
Numbers	37	10	119
Biomass	12	4	52

Zooplankton abundance between the affected and unaffected areas did not show any consistent variation. These being organisms with feeble locomotory powers get carried with water movements to the affected area. Further, determination of the period of sojourn of these populations in the polluted waters would be difficult and therefore, sublethal effects, if any, would be too subtle to be demonstrated. Qualitative analysis of zooplankton also failed to specify any indicator species associated with polluted water.

Investigation on the effluent disposal area of TiO_2 factory off Helgoland[6] showed emigration of new species into the area which gradually tended to outnumber the common species. In the present investigation, no similar gross ecological changes or dominance of any particular group of organism in the polluted environment were observed. This alongwith the recovery of faunal abundance at a particular zone when it becomes free of the effluent due to change in the direction of the drift indicates that a radical transformation of the ecology of the system had not been brought about yet, although the long term accumulation of pollutants and its sublethal effects could well alter ecosystems irretrievably.

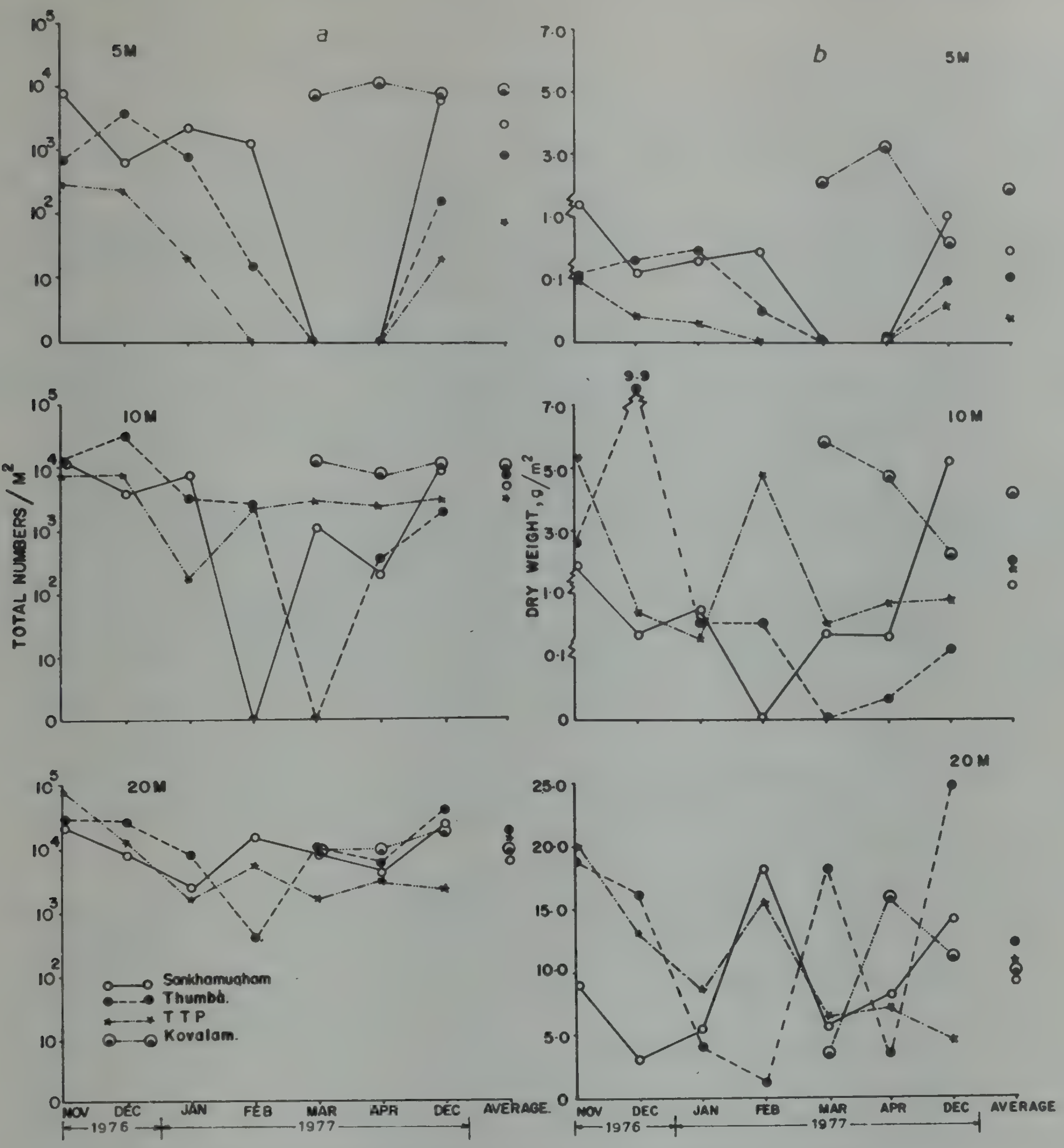

Fig. 2—Distribution of (a) total number and (b) biomass of benthos at 5, 10 and 20 m depths at different stations

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Hydrography, Chlorophyll & Plankton of the Kuwaiti Coastal Waters

P G JACOB, MAZIN A ZARBA & V ANDERLINI

Marine Pollution Programme, Environmental & Earth Sciences Division, Kuwait Institute for Scientific Research, P O Box 12009, Safat, Kuwait

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Seasonal and spatial fluctuations in chlorophyll, phyto and zooplankton standing stock and species composition together with physical and chemical oceanographic parameters in the coastal waters of Kuwait during March to May 1978 are reported. The values range from: chlorophyll *a*, 0.195 to 13.87 mg/m^3; total chlorophyll, 0.7 to 135.9 mg/m^3; total phytoplankton cell counts, 0.014 to 414.3 million cells/m^3; zooplankton volume, 0.04 to 2.1 ml/m^3; and zooplankton numbers, 15-3149/m^3. Areawise averages and ranges for all the observed parameters are also calculated and compared. Ratio of phytoplankton standing stock to zooplankton standing stock is 1.06 which proves that comparatively high rate of primary productivity in the study area is insufficient for supporting the zooplankton standing stock.

Information on plankton and hydrography of the Arabian Gulf, especially of its northwestern point is very limited. The Arabian Gulf is a marginal sea (*c* 1000 km length and 200-300 km width) covering an area of 226000 km^2 with a water volume of about 6000 km^3 and an average depth of 35 m (ref. 1, 2). It is an almost enclosed sea surrounded by arid desert lands and connected to the Indian Ocean through the Gulf of Oman by the narrow straits of Hormuz of 60 km width. The Tigris-Euphrates-Karun rivers, which join in Shatt A1-Arab, give the Arabian Gulf considerable fresh water influx at the north west end. But, the high loss of water in the Gulf through evaporation is not compensated by the river inflow, or by precipitation. Shatt A1-Arab has only a local effect on the marine environment[3]. During summer, the surface waters attain a temperature > 36°C in the coastal areas, and the Arabian Gulf is considered to be the warmest sea area during this period[4]. Winter temperatures are usually < 20°C (ref. 5). Salinity of the surface layer is 40.6‰ near the northwest end, while it is about 36.6‰ near the straits of Hormuz. Midwinter salinity in some of the interior bays reaches up to 52.4‰[6].

Kuwait is situated at the head of the Arabian Gulf (Fig. 1). It's Gulf coastline is about 200 km. Rapid coastal urbanisation, sewage effluents, industrial wastes and highly saline waste water discharged from the desalination plants are all creating ecological problems in the Kuwaiti coastal environment. The actual effects of these industrial and domestic wastes on the marine life is little known, except for limited studies[7]. The present investigation is a preliminary attempt towards detailed monitoring of changes induced by the effluents in the marine plankton population of these coastal waters.

Materials and Methods

During the present investigation (March to May 1978) samples from 81 stations of the coastal waters of Kuwait were collected (Fig. 1) during day-time. Majority of sampling sites were close to the coast, within the 20 m isobath with a maximum offshore distance of 14 km.

An *in situ* water checker (NERA-4 SURVEYOUR) of Hydrolab company was used for the determination of temperature, salinity, dissolved oxygen and *p*H of

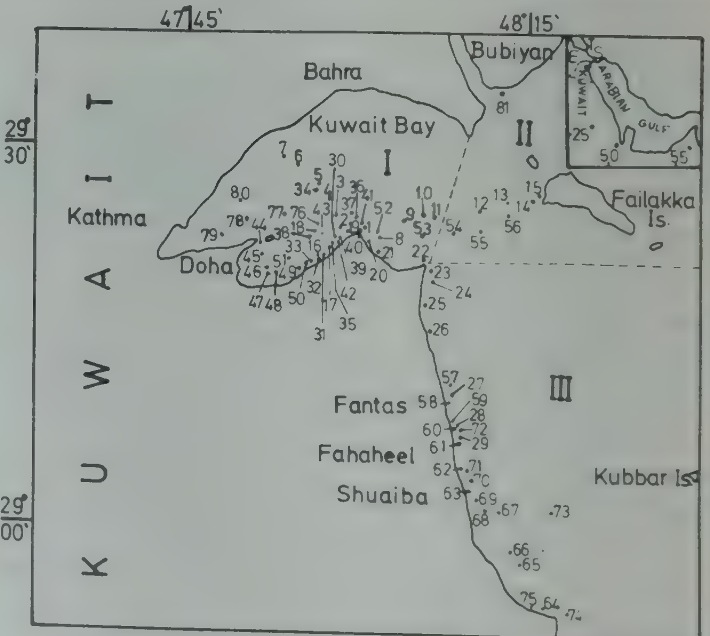

Fig. 1—Location of the stations (Inset: situation of Kuwait relative to the Arabian Gulf; E, T and S stand for the rivers Euphrates, Tigris and Shatt Al-Arab respectively)

the surface waters. Surface water samples were collected for the determination of chlorophyll (chl) *a*,*b* and *c* following the method of Strickland and Parsons[8]. Phytoplankton standing stock and qualitative analyses were carried out from surface water samples using the sedimentation chamber method devised by Tungate[9].

Zooplankton samples were taken with a 328 μm North Pacific Ocean Standard Net (NORPAC) fitted with a Kahlsico flowmeter. Horizontal hauls of 5 min durations were taken for each sample. Quantitative and qualitative analyses of the zooplankton were done following standard methods[10].

In order to compare roughly the standing stock of phytoplankton and zooplankton, biomass values were computed as mg C/m^3. Phytoplankton cell counts were converted to mg C/m^3 using the factor 61.97×10^{-8} mg C/cell[11]. For zooplankton, the conversion factor was 65 mg C/ml of zooplankton displacement volume[12]. Rough estimates of phytoplankton production in terms of g C/m^3/day were done using the factor g C/m^3/day $= 2 \times$ g total chlorophyll/m^3 $\times$ photoperiod in hr/day where photoperiod was taken as 12 (ref. 13).

Results and Discussion

Results have been pooled seasonally and spatially. Averages and ranges of chlorophyll, plankton and other physico-chemical parameters of the surface waters are given in Table 1. Highest average values for dissolved oxygen, chl *a*,*b* and *c*, total chlorophyll and porotzoan counts were during March. Highest average values for salinity, *p*H and phytoplankton cell counts were during April, while temperature and zooplankton volume and numbers were maximum during May. Chl *b* value and protozoan counts had maximum ranges during March-April and March respectively. Temperature, salinity, dissolved oxygen, *p*H, chl *a* and *c*, total chlorophyll and phytoplankton cell counts and zooplankton numbers had highest ranges during April, whereas the highest range for zooplankton volume was during May.

Fig. 1 shows that the sampling sites generally fall into 3 distinct areas, viz. I—the semienclosed Kuwait Bay; II—a more open sea area directly influenced by Shatt A1-Arab river inflow consisting of Failaka west and Bubiyan south; and III—the open sea area consisting of the eastern coast of Kuwait extending from Salmiya to Ras-A1-Quilla. These 3 areas offer different ecological niches. Therefore, the results of the various observations from stations falling in these different areas were pooled and their averages and ranges calculated for comparison. Maximum average surface salinity, *p*H and phytoplankton cell counts were recorded from area III. Area II had the maximum average value of chl *b* and *c* and total chlorophyll, zooplankton numbers and the minimum numbers of planktonic protozoans and phytoplankton cell counts. Area I had the maximum average of surface dissolved oxygen, chl *a*, zooplankton volume and protozoan counts. Average zooplankton numbers, volume, dissolved oxygen value and chlorophyll values were lowest in area III. High average values of chlorophylls in area I and II might be due to the eutrophication brought about by the organic wastes coming from the Kuwait city and other urban centers along the southern coast of Kuwait. Basson *et al.*[6] also reported that phytoplankton cell counts are higher in interior bays of the Arabian Gulf than in the nearshore or offshore areas because of nutrient enrichment. Even though zooplankton volume was the highest in the Bay, total number of zooplankton was not as high as in area II indicating the occurrence of comparatively larger zooplanktonic forms like medusae in the Bay area.

Table 1 reveals that phytoplankton cell counts do not show any noticeable relationship with chlorophyll values. Therefore, it must be assumed that the major factor which contributes to the primary production is nannoplanktonic phytoplankton or 'smaller phytoplankton', which are not readily counted by the conventional methods. Similar results have been reported from the west coast of India[14]. Occasionally, 50-100% of the primary producers reported are nannoplanktonic forms in some regions of the west coast of India. Pant *et al.*[11] have reported that nannoplankton is an important part of the waters of Goa (west coast of India) which may be responsible for up to 90% of primary production. Table 2 shows that *Asterionella japonica* is the most important constituent in the phytoplankton community, closely followed by genera like *Rhizosolenia* and *Chaetoceros*. Other important constituents are genera like *Eucampia*, *Thalassiosira*, *Pleurosigma*, *Coscinodiscus*, *Prorocentrum*, *Thalassiothrix*, *Bacteriosira*, *Asterionella*, *Ceratium*, *Pyrocystis*, *Ceratulina*, *Nitzschia*, *Fragilaria*, *Navicula*, *Biddulphia* and *Noctiluca*. At some of the stations, especially in the Kuwait Bay, individual species like *Asterionella japonica*, *Rhizosolenia styliformis*, *Chaetoceros* sp, *Pleurosigma* sp and *Thalassiosira* sp form > 90% of the total constituents indicating their individual blooms. The coloration caused by such blooms is visible on many occasions. Basson *et al.*[6] have reported that in the interior bays of the Arabian Gulf coast of Saudi Arabia, like Tarut, al-Uqayr, al-Mussallamiyah and al-Musharriah, the average annual diversity index of phytoplankton species is lowest (0.869) compared to offshore (0.895) and nearshore (0.930) areas. Larger seasonal changes in temperature and salinity in the Arabian Gulf bays

Table 1—Average and Range (in paranthesis) of Chlorophyll, Plankton and Other Physico-chemical Parameters of the Surface Waters of the Kuwaiti Coast during March to May 1978

	Chl *a* mg/m³	Chl *b* mg/m³	Chl *c* mg/m³	Total chl mg/m³	Phyto-plankton million cells/m³	Zoo-plankton volume ml/m³	Zoo-plankton Nos/m³	Proto-zoans million cells/m³	Temper-ature °C	Salinity ‰	Dissol-ved oxygen mg/l	*p*H
							Month					
March	5 (0.2-9.2)	7.5 (0-32.7)	25.1 (2.1-94.8)	37.1 (2.3-135.6)	12.4 (0.01-63.4)	0.3 (0.04-1.45)	793 (41-2575)	0.7 (0-1.70)	21.1 (18.9-24.5)	29.9 (22.7-36.8)	10.2 (9.2-11)	8.1 (7.8-8.5)
April	4 (0.5-13.9)	7.6 (0-32.7)	22.2 (0.9-94.8)	36.8 (2.4-135.9)	57.9 (0.13-414.3)	0.2 (0.01-0.75)	590 (19-3114)	0.03 (0-0.60)	22.6 (19.2-27.0)	37 (21.3-39.6)	7.1 (5.4-9.4)	8.4 (8.1-9.9)
May	4.7 (0.4-5.2)	2.7 (0.2-9)	7.3 (0-29.8)	13.7 (0.7-34.2)	7.1 (0.49-27.2)	0.5 (0.1-2.1)	1941 (361-3149)	0.01 (0-0.04)	26.5 (23.5-26.6)	34 (24.5-39.9)	6.9 (6.4-7.5)	8.3 (8.2-8.3)
							Location					
Area I	5.2 (0.2-13.9)	8.7 (0-32.7)	27.6 (0-94.8)	41.2 (0.7-135.6)	15.3 (0.06-280.9)	0.4 (0.05-2.1)	873 (15-3114)	0.06 (0-1.70)	22.2 (18.9-26)	35.2 (22.7-39.9)	8.2 (6.2-11)	8.2 (7.8-9)
Area II	4.4 (0.5-8.2)	8.9 (0-32.7)	29.8 (0.9-94.8)	43.1 (3.6-135.6)	1.4 (0.01-6.9)	0.3 (0.08-0.45)	1418 (543-3149)	0.001 (0-0.01)	22.6 (20.4-27.2)	32.7 (21.3-37.6)	6.9	8.3 (8.2-8.4)
Area III	3.4 (0.2-7.9)	6.4 (0-32.7)	19.9 (0.9-94.8)	31.5 (2.3-135.4)	62.3 (0.3-414.3)	0.2 (0.04-0.75)	313 (41-1522)	0.05 (0-0.6)	23.5 (21-27)	37.4 (35.5-39.6)	6.7 (5.4-9.4)	8.6 (8.1-9.4)
Total (Data from all stations)	4.4 (0.2-13.9)	7.5 (0-32.7)	24.2 (0-94.8)	36.1 (0.7-135.9)	30.1 (0.01-414.3)	0.3 (0.04-2.1)	724 (15-3149)	0.05 (0-1.70)	22 (18-27)	35.9 (21.3-39.9)	7.5 (5.4-11)	8.4 (7.8-9.9)

constitute a less stable environment eliminating many species unable to adapt to the changed environment. This reduces the taxonomic diversity and produces blooms of selected species of phytoplankton which tolerate wide fluctuations in the environmental conditions.

Among zooplankton calanoid copepods were the major constituent (Table 2). Their maximum average was 57.64% in the zooplankton followed by crustacean larvae and other crustaceans, excluding gammarids. Other important constituents in the zooplankton were chaetognaths, fish eggs, planktonic gastropods and gastropod larvae, Oikopleura, lamellibranch larvae, fish larvae, gammarids, medusae, polychaete adults and larvae, pleurobrachia and other ctenophores.

Along with the qualitative analysis of phytoplankton samples, protozoans encountered were also recorded. Most of the protozoans were identified from their shells only. Loricae of tintinnids were the most important constituent (0.047 million cells/m³) followed by radiolarians (0.0013 million cells/m³) and foraminifers (0.001 million cells/m³).

Chlorophyll values and phytoplankton production (total average 0.867 g C/m³/day) show that the Kuwaiti coastal waters are more productive than some of the highly productive regions of the Indian coast[16,17]. However, even this high rate of primary productivity seems to be insufficient for supporting the high zooplankton standing stock of this region (Fig. 2). Therefore, except perhaps in area III, the energy budget of the zooplankton trophic level might be supplemented by detritus and bacterial components of the ecosystem during the observation period of the year.

Table 2—Percentage Composition of Plankton in Samples

Phytoplankton

Species	Percentage
Asterionella japonica	30
Rhizosolenia spp	22
Chaetoceros spp	21
Eucampia spp	6
Thalassiosira spp	5
Pleurosigma spp	4
Coscinodiscus spp	2
Prorocentrum spp	2
Thalassiothrix spp	2
Bacteriosira sp.	1
Asterionella sp.	1
Ceratium spp	1
Pyrocystis sp.	1
Ceratulina spp	0.3
Nitzschia sp.	0.2
Fragilaria sp.	0.1
Navicula spp	0.1
Biddulphia spp	0.04
Noctiluca sp.	0.001

Zooplankton

Species	Percentage
Copepods	58
Crustacean Larvae and other crustaceans excluding gammarids	26
Chaetognaths	3
Fish eggs	3
Gastropod juveniles	2
Oikopleura	2
Lamellibranch juveniles	2
Fish larvae	1
Gammarids	1
Medusae	1
Polychaetes	0.8
Pleurobrachia	0.03
Other ctenophores	0.01

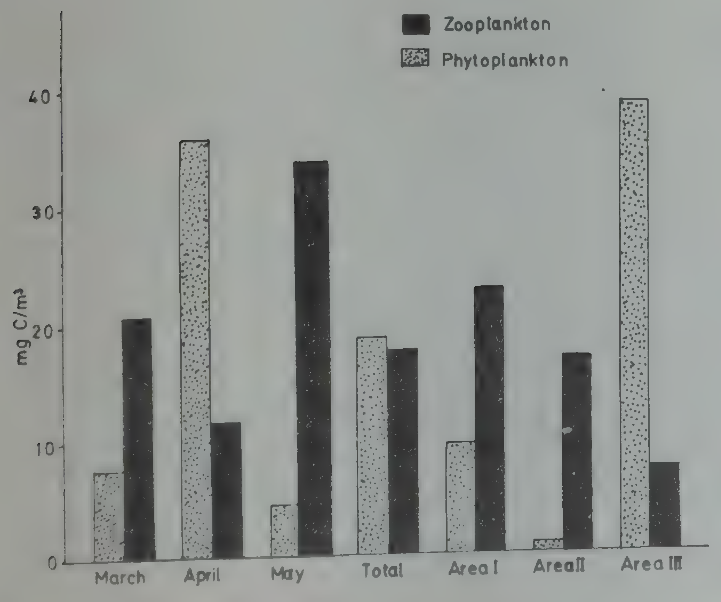

Fig. 2—Standing stock of phytoplankton and zooplankton expressed as mg C/m³ of the Kuwaiti surface waters during 1978

Chlorophyll values observed are generally higher than the values reported by Al-Saadi *et al.*[18] from the Shatt Al-Arab mouth area of the Arabian Gulf during October 1975. But the phytoplankton cell counts obtained during the present investigation are generally similar to the values reported by Al-Kaisi[19]. However, the seasons of observation are different in these studies. The values reported by Basson *et al.*[6] are higher than the present values and those of Al-Kaisi[19]. It has been reported that the dominant forms of phytoplankton in the Kuwaiti waters were diatoms like *Rhizosolenia* spp and *Chaetoceros* spp and that some of these have blooms[19-21]. The present findings also are in agreement with their observations.

Zooplankton volumes and counts per m^3 observed during the present study are in general agreement with the values reported by Yamazi[22]. The percentage of different zooplankton taxa also, especially those of copepods (52.4% average), is similar to the average values observed in the present study (57.6%).

Crisp[23] has observed that because of the shallowness of the Arabian Gulf, the zooplankton contains a high proportion of the larvae of bottom living invertebrates. During the present study also, the second important group of zooplankton other than copepods, are larval forms of polychaetes, crustaceans, gastropods and lamellibranchs. Among crustacean larvae the most abundant forms are brachyuran zoea, followed by penaeid larvae from the northern regions, especially Bubiyan island waters. Yamazi[22] has observed that the zooplankton biomass in the Arabian Gulf is formulated by mixed communities of neritic and oceanic forms of larger size and inlet water forms of smaller size, both habitually being adapted to the environments of high temperature and salinity. The carnivorous planktonic forms represented by medusae, gastropods, chaetognaths and others form a considerable portion of the total zooplankton in these waters. Taking into account the shallowness and isolation of the Arabian Gulf, the trophodynamics of the animal communities in the presence of such a large proportion of carnivorous forms, even in the zooplankton community is an interesting subject to explore.

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Biochemical Studies on Some Tropical Estuarine Zooplankton Species

M MADHUPRATAP, P VENUGOPAL* & P HARIDAS*
National Institute of Oceanography, Dona Paula, Goa 403 004

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Percentages of protein, carbohydrate and lipid which form the major biochemical constituents of 10 species of zooplankton from Cochin backwaters were estimated. Protein invariably formed the major constituent in terms of dry weight. Carbohydrate content was in general very poor. Both protein and lipid were low for organisms with higher water content and did not show any reciprocal relationship. The results in general supported the view that protein may function as a metabolic reserve in zooplankton and that the availability of a constant supply of food may render large amount of lipid storage unnecessary in tropical zooplankton.

Information on biochemical composition of tropical zooplankton especially from Indian waters is meagre. Estimation of biochemical constituents of zooplankton is important in understanding their physiological functions, metabolism and nutritive value which are relevant to the marine ecosystem, in its energy transfer and secondary production. In this paper major biochemical constituents of 10 zooplankton species from Cochin backwaters, are presented.

Materials and Methods

Zooplankton was collected from the mouth of the estuary using a square net and was brought immediately to the laboratory live. Most of the species which are high saline (optimum range—20 to 30‰) were collected during March-April 1978 when the estuary attained its climax community. Two copepod species *Pseudodiaptomus annandalei* and *Acartia plumosa* which are medium saline (15-25‰) and the sergestid *Acetes cochinensis* which tolerates wide salinity fluctuation were collected, during May.

All species except copepods were identified live and estimations made within a few hours of capture. Copepods were deep frozen, thawed later and rapidly sorted in cold water for estimations. All estimations for a species were made from animals of the same haul except for copepods. Estimation of protein was made by biuret method[1], carbohydrate by the method of Dubois *et al.*[2], as modified and described by Raymont *et al.*[1], total lipid by the gravimetric method of Folch *et al.*[3] and total organic carbon by E1 Wakeel and Riley[4] method. Dry weight percentages of individual species was obtained after drying them to constant weight at 60°C[5].

Results

The results are presented in Table 1.

Protein formed the major constituent in all species investigated. Protein content was comparatively low in organisms with high water content such as ctenophora and hydromedusae and ranged between 30 and 40% in terms of dry weight. In other species it ranged between 50.9% (in *Acartia centrura*) and 77% (in *Acartia plumosa*).

Carbohydrate content was extremely low and ranged between 0.39 and 4.18% in terms of dry weight. The value 4.18 obtained for *Acartia plumosa* should be treated with some bias since the specimens of this species had some algal particles sticking to their appendages which could not be completely removed inspite of repeated washings and the high carbohydrate content could be an artifact due to this. Lipid content was very low for the more watery organisms (ctenophora, hydromedusae and chaetognatha) and ranged from 6.02 to 8.91% in terms of dry weight. It was also on the lowerside for other species (9.23 to 14.12%) compared to reported values for zooplankton from higher latitudes. Total organic carbon was estimated for mixed zooplankton (gelatinous and non gelatinous separately) and the average of 4 estimates was 5.1% for the former and 33.1% for the latter in terms of dry weight.

Discussion

Considerable seasonal variation in the biochemical fractions of zooplankton from higher latitudes as well as warm waters have been reported[6-10]. But in the Cochin backwaters, occurrence of various species is by itself seasonal, the high saline species investigated occur only during the premonsoon period (December-April) when the estuary becomes saline[11]. However, in

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*Present address: Regional Centre of NIO, Cochin 682 018

Table 1 — Protein, Carbohydrate and Lipid Content and Dry Weight Percentages of 10 Zooplankton Species from Cochin Backwaters

[Values are expressed as per cent wet weight (WW) or dry weight (DW)]

	Protein		Carbohydrate		Lipid		Percentage of dry weight
	WW	DW	WW	DW	WW	DW	
Ctenophora							
Pleurobrachia globosa	1.63	39.77	0.03	0.64	0.25	6.02	4.09
Hydromedusae							
Eirene ceylonensis	0.81	30.34	0.01	0.39	0.27	8.11	3.44
Eutima commensalis	0.86	35.69	0.04	1.96	0.34	8.91	2.43
Blackfordia virginica	0.98	32.11	0.02	0.58	0.27	8.72	3.07
Chaetognatha							
Sagitta enflata	8.33	75.83	0.16	1.47	0.69	6.32	10.99
Copepoda							
Pseudodiaptomus annandalei	11.12	74.79	0.29	1.94	1.71	11.53	14.88
Acartia centrura	8.57	50.93	0.17	1.02	2.21	14.12	16.83
A. plumosa	10.60	77.00	0.63	4.18	No data		13.32
Sergestidae							
Lucifer hanseni	8.77	65.22	0.41	3.03	1.12	9.23	13.44
Acetes cochinensis	14.45	75.67	0.43	2.14	2.48	12.37	20.15

tropical waters zooplankton have comparatively shorter life span than cold water species. Hence several generations can occur within short periods and variations in biochemical composition between generations would need further investigation.

It is fairly well established that protein forms the major fraction in terms of dry weight in zooplankton. Mean values in terms of dry weight given by Raymont *et al.*[1,8,12] are 57% in the euphasid *Meganyctiphanes norvegica*, 58% in several decapods, 60% in several oceanic decapod plankton and 70.9% in the mysid *Neomysis intiger*. Reeve *et al.*[10] have given the mean protein content of the chaetognath *Sagitta hispida* as 52.9% and Mayzaud and Martin[13] have reported 54.2% for the chaetognath *S. elegans* and 44.5% for the copepod *Calanus finmarchicus*. Nakai[14] has given the range of protein from 34.8% for the copepod *Calanus plumchrus* to 82.6 in *Acartia clausi*. Ferguson and Raymont[9] have reported protein values for the euphasid *Euphasia superba* ranging from 37 to 56.3%. From Cochin backwaters Nair *et al.*[15] have reported 64.4% for the chaetognath *Sagitta bedoti* and a range of 52.4 to 63.9% for some other groups of zooplankton. The protein fractions of species in the present study also fall within the above ranges except for the ctenophora *Pleurobrachia globosa* and the species belonging to hydromedusae. Comparable studies for these groups of organisms seem to be lacking.

Reciprocal relationship has been observed between protein and lipid fractions[7,14] but such a relationship was generally not apparent in the present study. Total lipid content was generally low compared to reported mean values from colder waters, but was usually close to the lower values of the ranges (10 to 29—*Meganyctiphanes norvegica*, 16 to 34—*Euphasia superba*, 9 to 15—*Neomysis intiger*). Raymont *et al.*[12] reported the lipid content of *Sergestes* sp. as 29% and Reeve *et al.*[10] gave the lipid range of *Sagitta hispida* as 9 to 27 with 17 as the mean percentage. Absence of a reciprocal relationship between protein and lipid was especially noticeable in ctenophora and hydromedusae in which both protein and lipid content was very low. Lee[16] also observed comparatively low lipid content for the ctenophores *Pleurobrachia pileus* (9%) and *Beroe cucumis* (14%) compared to copepod species which had a high lipid content (*Calanus finmarchicus*—47%). Conover and Corner[17] observed the lipid changes of the cold water oceanic copepod *Calanus hyperboreus* to vary from 15 to 50% of dry weight and Conover[18,19] found that the lipid content of this species may increase to as much as 60%. Lee and Hirota[20] suggested a geographical pattern in the distribution of lipid among copepods and an increase in lipid content with deep water and high latitude species compared with species in near surface waters or low latitudes.

The general low carbohydrate content in zooplankton led to contemplations on the functional role of other biochemical fractions in their metabolism. Raymont and Conover[21] felt that the carbohydrate from the food may be oxidised directly by zooplankton or that fats may be oxidised on need or stored as principal reserve food. Later evidences indicated that the neutral lipids available for metabolic purposes would not amount to more than a fraction of the total lipids and hence the animals would have to feed more or less continuously to fulfill their immediate needs[22]. Considering these, it was felt that although lipid would function as an important food reserve, protein may also be utilised and function as a reserve food[7,10,17,19,23–25].

Studies on the mysid *Neomysis intiger*[26] indicated that on starvation amino acids from protein appear to be mobilised and subsequently deaminated with a rapid rise in ammonia excretion. Loss of protein in zooplankton under starved conditions indicating its utilisation have been demonstrated[10,24,25]. Mobilising protein for metabolic requirements would be especially true for tropical zooplankton like the species in the present study which have lower lipid content.

Lee[16] observed that ctenophores and *Sagitta* which had low fat content could be starved only for 48 hr after which they died, but copepods with high lipid content could be starved up to a month. He found that in both ctenophores and *Sagitta* triglycerides and wax esters (neutral lipids) were very low and that phospholipids (structural lipids) showed little variation in zooplankton species regardless of the changes in quantity or type of food. Copepods and *Lucifer* from Cochin backwaters survived in starved conditions in the laboratory only for 3 to 5 days[27]. Exceptionally high values of fat (60%) were reported for the isopod *Cirolana fluviatilis* from Cochin backwaters[28] and it is of interest that this species is not a continuous feeder[29]. Mayzaud and Martin[13] suggested that small neritic copepods because of their body size present a high level of turnover of their biomass apparently as an alternative of high storage and, therefore, do not contain large amount of lipid material. Lee and Hirota[20] pointed out that zooplankton of tropical region have more constant supply of food than in higher latitudes so that an elaborate structure for lipid storage is unnecessary for them. Lee *et al.*[30] found sharp variations in lipid content between surface living copepods (*Candacia curta*—3%) and deep water copepods (*Bathycalanus* sp—59%, *Heterorhabdus* sp—61%) and concluded that the function of protein as an important energy reserve may be true for zooplankton having low lipid content, but less important for the lower mesopelagic and bathypelagic copepods rich in lipid. The low lipid content observed in the species in the present study supports the view that protein may form a major metabolic reserve substrate in tropical zooplankton. It is also possible that the rich food supply available to the herbivores in the estuary[31] and carnivores like ctenophora, hydromedusae and chaetogtha during the saline period when zooplankton abound in the estuary[11] would render large lipid storage unnecessary for them.

The average organic carbon content of non gelatinous zooplankton compare well with the value of 30% reported for *Neomysis intiger*[6]. Low organic carbon content has been reported[32] for organisms (ctenophora—6.4%, salps—9.4%, cnidarians—13.8% to 31.4%) with high fresh to dry weight ratios as observed for gelatinous organisms.

The total recovery rates were low especially for gelatinous organisms which contain little chitin. Raymont *et al.*[23] have found that the non protein nitrogenous (NPN) fraction of *Neomysis intiger* varies with environmental salinity. Reeve *et al.*[10] attributed the low totalised figures they obtained for *Sagitta hispida* to the presence of NPN compounds which was highly variable (mean—37% of total nitrogen content) and concluded that variability of NPN was correlated with environmental salinity changes. The estuarine species in the present study withstood considerable salinity variations[11] and may have a ready high NPN content to cope with the wide fluctuations that occur in the estuary.

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Distribution of *Haloptilus* (Copepoda, Calanoida) in the Indian Ocean

K SARALA DEVI, ROSAMMA STEPHEN & T S S RAO*
National Institute of Oceanography, Regional Centre, Cochin 682018

Received 20 *February* 1979

Haloptilus specimens, collected during the International Indian Ocean Expedition, from 442 stations are examined. Of the 12 species encountered *H. paralongicirrus*, *H. austini*, *H. bulliceps*, *H. fertilis* and *H. fons* are new to the Indian Ocean. Most of the species are cosmopolitan in distribution, *H. longicornis* being the dominant species. Highest density of most of the species is noticed in the upwelling areas. *H. paralongicirrus* and *H. oxycephalus* show significant difference between day and night collections in southwest Indian Ocean during SW monsoon period. *H. ornatus* shows significant difference between day and night in Bay of Bengal during SW monsoon period. Comparison of number of specimens irrespective of diurnal and seasonal variations in different regions, viz. Arabian Sea, Bay of Bengal, southwest Indian Ocean and southeast Indian Ocean shows significant difference in the case of *H. paralongicirrus* and *H. spiniceps*. Arabian Sea has more number of specimens than Bay of Bengal and southwest and southeast Indian Ocean. *H. ornatus* shows more count in Bay of Bengal. Other species show no significant difference between regions. Comparison of 2 seasons irrespective of diurnal and regional variations shows significant difference only in the case of the dominant species *H. longicornis* for which NE monsoon shows more count than SW monsoon.

The genus *Haloptilus* is widely distributed[1]. Occurrence of this genus from scattered and restricted areas of the Indian Ocean has been reported[2-9]. Reports on this genus based on the International Indian Ocean Expedition (IIOE) material have also been made[10-12]. The present study on *Haloptilus* is from the zooplankton samples collected during IIOE (1960-1965).

Materials and Methods

Arabian Sea and Bay of Bengal received maximum coverage for sampling, the area being of special interest due to the effect of the monsoons. Representative samples from each 5° Marsden square were analysed to get a general idea about the distribution of different species. Altogether 442 standard samples[13] were examined in the present study. Distribution maps were prepared for common species. For comparison the samples were tentatively arranged into 4 groups according to the regions of collection [226 samples from Arabian Sea (I), 88 samples from Bay of Bengal (II), 97 samples from southwest Indian Ocean (III), and 31 samples from southeast Indian Ocean (IV)]. Comparisons between regions, day and night and periods (16th April-15th October, 16th October-15th April) were made. The data were subjected to statistical analysis using student *t* test and the significance of *t* value established[14]. Only those stations where specimens were available were included in the analysis.

Results and Discussion

Distribution of different species of *Haloptilus* (Figs 1 and 2) is given below.

H. longicornis—This is a very common and most dominant species representing 89.6% of the total samples and 84.3% of the genus. It is widely distributed in all parts of the Indian Ocean with high density along the western and central parts of the ocean. Maximum number (632/st. haul) is found in a station located along the southwest coast of India. It is moderately represented in the Bay of Bengal and southern Indian Ocean. Hydrographic conditions of the stations from where the species was collected show that it can tolerate temperature from 10.3-30.42°C, salinity 31.7-36.6°/₀₀ and dissolved oxygen 0.011-6.22 ml/litre.

The type locality of the species is the Mediterranean Sea. This is also recorded in Atlantic Ocean and adjacent seas from 70°N to the Antarctic Sea. The species has been recorded earlier in Indian Ocean from 14°N to 35°S and Pacific from 35°N to 40°S. Near Japan this seems to be present in warm currents.

H. paralongicirrus—It is present in 38% of the total samples and constitutes 4.27% of the genus. Maximum number (26/st. haul) is observed in a sample collected from a station located at 04°22′S and 67°24′E during SW monsoon. Patches of high distribution are noticed at the mouth of Gulf of Oman, southeastern

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*Present address: National Institute of Oceanography, Dona Paula, Goa 403004

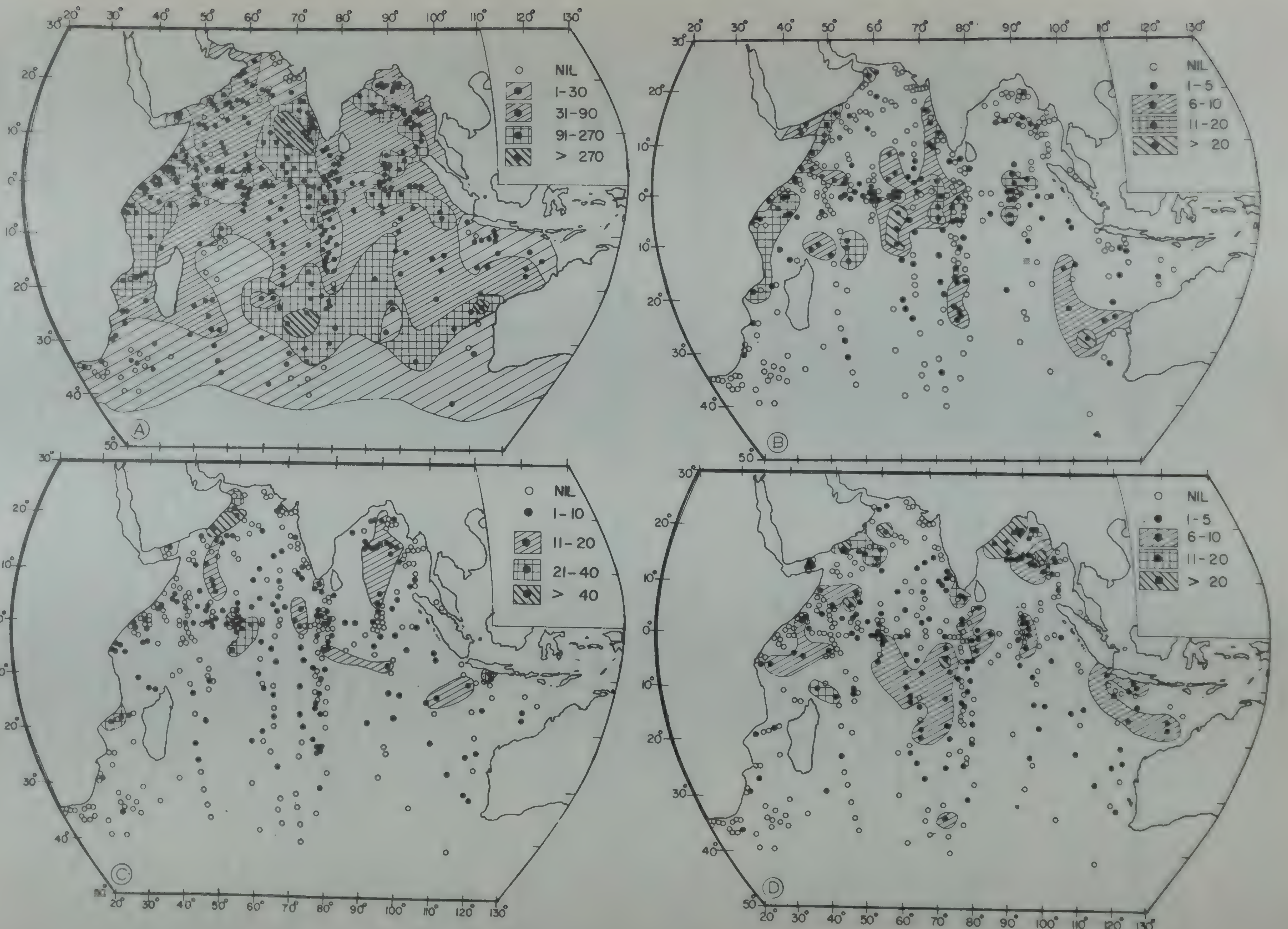
A
○ NIL
1-30
31-90
91-270
> 270
B
○ NIL
● 1-5
6-10
11-20
> 20
C
○ NIL
● 1-10
11-20
21-40
> 40
D
○ NIL
● 1-5
6-10
11-20
> 20

Fig. 1—Distribution of (A) *H. longicornis*, (B) *H. paralongicirrus*, (C) *H. spiniceps* and (D) *H. ornatus*

Arabian Sea and near Australian coast around 110°E and 27°S. Moderate values are observed in the equatorial belt between 10°N and 10°S, in the Gulf of Aden and Mozambique coasts. It is sparsely represented in the northern and southern parts of the ocean. This species occurs at temperature 11.85-29.3°C, salinity 31.71-35.87‰ and dissolved oxygen 0.58-6.22 ml/litre. The type locality of the species is Carribbean Sea. This is the second record of the species from world oceans and the first from the Indian Ocean.

H spiniceps—This species is present in 47% of the total sample and it constitutes 5.33% of the genus. Patches of moderate distribution are seen on the equatorial belt, central Arabian Sea and near Djkartha. Area of highest density is located in the northern Arabian Sea between 17°18′N-61°15′E. Maximum number (125/st. haul) is seen in a station located at 20°44′N and 61°15′E, during NE monsoon.

In the southern Indian Ocean this species is represented in small numbers. It is more abundant north of 10°S. It tolerates temperature between 11.24° and 30°C, salinity 32.22 and 36.6‰ and dissolved oxygen 0.13 and 5.78 ml/litre. *H. spiniceps* is first recorded from Mediterranean Sea. In Atlantic it is reported between 50°N and 28°S and in the Pacific from 38°N to 34°S. In the Indian Ocean it is so far been recorded in the eastern and western sides between the Equator and 35°S. This seems to be the first record of the species from the northern hemisphere in the Indian Ocean.

H. ornatus—This constitutes 24.4% of the total samples and 3.87% of the genus. It is distributed all over the Indian Ocean. Isolated patches of high distribution are observed in the Arabian coast. Maximum number (39/st. haul) is found in a station located between 04°11′S and 75°00′E in the Bay of Bengal. On the whole, Bay of Bengal is highly populated than the Arabian Sea. moderate distribution is noticed between 0 and 20°S. South of this region the species is represented in small numbers. It occurs in a range of temperature 11.33°-29.94°C, salinity 32.7-36.35‰ and dissolved oxygen 0.18-5.78 ml/litre.

First record of this species is from Mediterranean Sea. It is wide spread in the Atlantic between 38°N and 27°S and in the Pacific between 35°N and 20°S. Early records of the species from western Indian Ocean are from 10°N to 30°S and in the eastern Indian Ocean from Malay Archipelago.

H. oxycephalus—This species is present only in 12.4% of total samples and 0.87% of the total genus.

The species is more abundant along the equatorial region. It is sparsely distributed in the central Arabian Sea. Patches of high distribution are noticed in the central part of Bay of Bengal. It is also represented in the southern Indian Ocean. Maximum number (29/st. haul) is found in a station at 18°S and 70°E. Hydrographic conditions of the station show that *H. oxycephalus* can tolerate temperature from 12.25°-29.64°C, salinity 33.35-36‰ and dissolved oxygen 0.11-5.88 ml/litre.

This species is originally reported from Atlantic Ocean. In the Pacific this species extends to Antarctic region up to 78°S. The species is recorded in the western Indian Ocean from 0-35°S. This is the first record of the species from the eastern Indian Ocean.

H. mucronatus—This species is present only in 5.66% of the samples and constitutes 0.15% of the genus. Better representation of the species is seen in the northern part of the ocean especially in the equatorial region, south of 10°S, it is present only in 3 stations. Patches of high distribution are noticed in the Arabian coast, Gulf of Aden, Somali coast and African coast. It is completely absent in the southern Indian Ocean. Maximum number (25/st. haul) is in a station located at 03°00′S and 53°00′E. This species can tolerate temperature from 12.53°-30.37°C, salinity 32.74-37.36‰ and dissolved oxygen 0.15-5.59 ml/litre.

H. mucronatus is first reported from the Mediterranean Sea. In Atlantic it occurs between 37°N and 25°S. In Pacific between 30°N and 34°S and in the Indian Ocean it has been so far recorded only from the western side of the ocean up to 27°S. The present record extends up to 30°S in the western Indian Ocean. This is the first record of the species from Bay of Bengal and from the eastern Indian Ocean.

H. austini—This species is represented in 11.5% of the total sample and 0.43% of the genus. In the Arabian Sea *H. austini* is observed off the Arabian coast, at the mouth of Gulf of Oman, in the Gulf of Aden and off the southwest coast of India. It is completely absent along the east coast of Africa in the northern and central part of Bay of Bengal. South of Equator up to 35°S this species shows a scattered distribution. Maximum number (13/st. haul) is observed in a station located off Arabian coast.

H. austini is originally reported from the equatorial and subtropical regions of east central Pacific Ocean. Earlier records are from the northern hemisphere, from the central and western Atlantic between 0 and 40°N and from the central Pacific between 0 and 28°N. This is reported here for the first time from the Indian Ocean, occurring between 24°N and 35°S. This species occurs at a temperature range of 11.2-30.0°C, salinity 34.09-36.25‰ and dissolved oxygen 0.25-6.22 ml/litre.

H. acutifrons—It's presence is noticed in 9.3% of the total samples and 0.34% of the genus. Maximum representation is in the northern Indian Ocean than in

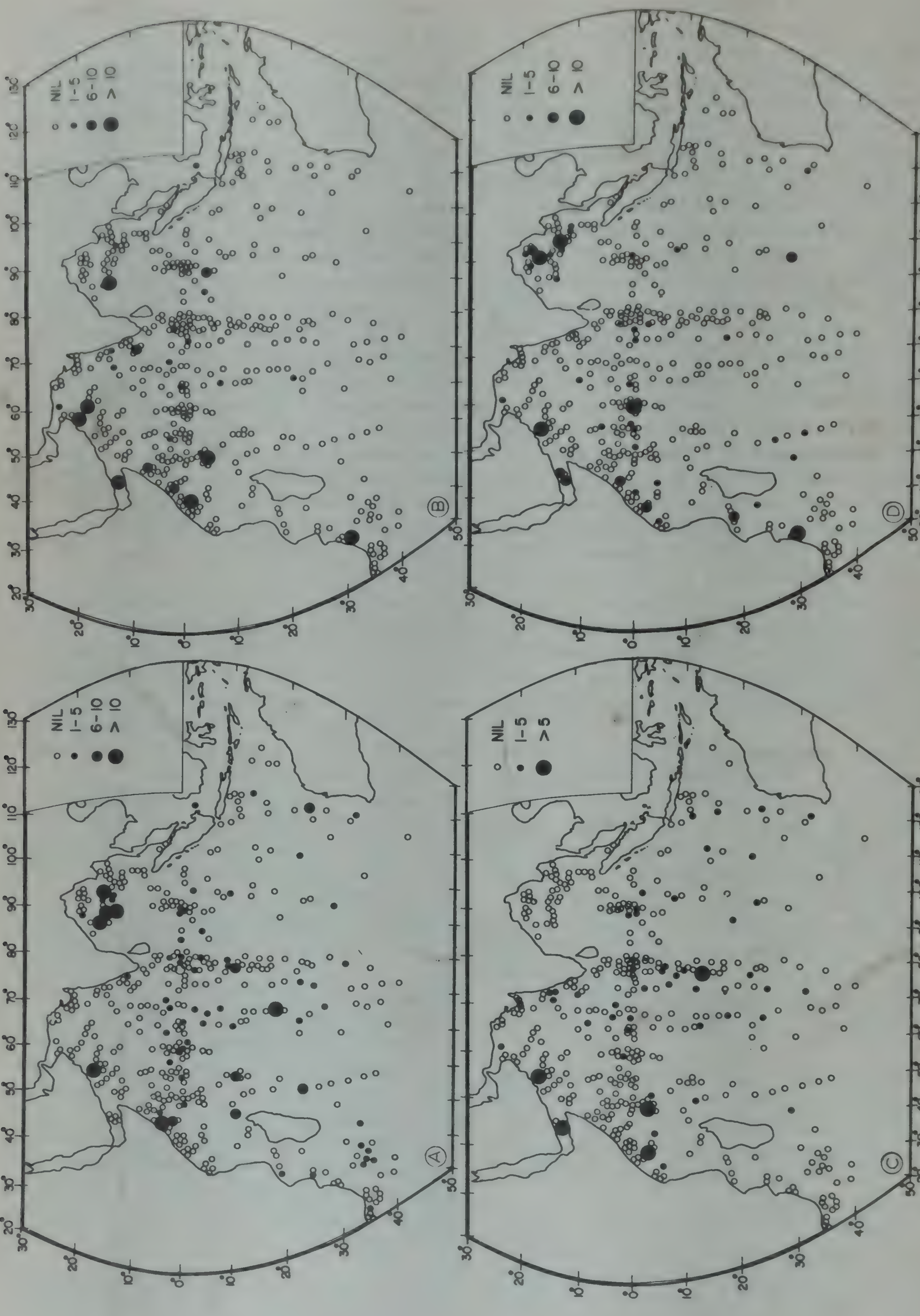
A
B
C
D
NIL
1-5
6-10
> 10
NIL
1-5
> 5
20°
30°
40°
50°
60°
70°
80°
90°
100°
110°
120°
130°
10°
0°

Fig. 2—Distribution of (A) *H. oxycephalus*, (B) *H. mucronatus*, (C) *H. austini*, and (D) *H. acutifrons*

the southern region where it's representation is scattered. High values are seen off the coast of Arabia, Bay of Bengal and in the equatorial region between 65 and 70°E. Maximum number (14/st. haul) is found in a station located in the southwest Indian Ocean, along African coast. The range of tolerance of temperature salinity and dissolved oxygen is between 11.24-29.76°C, 31.7 and 36.25°/₀₀ and 0.14 and 5.86 ml/litre respectively.

First record of the species is from Mediterranean Sea. It is wide spread in the Atlantic and Pacific. Earlier records of the species from the Indian Ocean extends from 24-35°S.

H. chierchiae—This species is found at 2 stations, one in the Gulf of Oman and another in the central part of Arabian Sea. Temperature, salinity and oxygen of the 2 stations range from 14.66-29.44°C, 34.8-36.25°/₀₀, 0.13-5.57 ml/litre respectively.

Type locality of the species is northern Atlantic. It occurs in southeast Pacific from the Equator to 17°S. Former records of the species from the Indian Ocean are between 6°N and 18°N. Present record also is from the northern Indian Ocean.

H. bulliceps—Six specimens, stage IV female, are obtained from 4 collections taken from 3 regions, viz. Bay of Bengal, southern Indian Ocean and southeastern Indian Ocean. Three specimens are observed in a sample collected from off the coast of Australia. This species tolerates temperature between 11.54 and 29.30°C, salinity 32.71 and 35.87°/₀₀ and oxygen 0.58 and 6.22 ml/litre.

The original record of the species is based on stage IV female from Atlantic Ocean. This is the first record of the species from the Indian Ocean.

H. fertilis—One male specimen of *H. fertilis* is obtained from sample collected by the ship *Vitiaz* from the area between 28°18′S and 62°33′E. The first record of the species is from Atlantic between 25°N and 28°N. In the Pacific it is reported only in the northern hemisphere. The present record is the first one from Indian Ocean.

H. fons—Two stage V and 1 stage IV female specimens are obtained from 3 stations along 110°E meridian at 15°30′S, 18°30′S and 27°30′S latitude respectively. This forms the first record of the species from the Indian Ocean. The Atlantic and Pacific records were based on adult specimens.

Table 1—Comparison of Day and Night in Different Regions for 8 Species of *Haloptilus* for the Two Seasons

[Values represent No./st. haul]

	SW monsoon		NE monsoon	
	Night mean	Day mean	Night mean	Day mean
H. longicornis				
Region I	1.5137	1.6766	1.6339	1.7983
Region II	1.2628	1.8068	1.4673	1.5689
Region III	1.4452	1.3862	1.7525	1.6343
Region IV	1.5030	1.6520	1.4861	1.4813
H. paralongicirrus				
Region I	0.8500	0.8380	0.8469	0.8197
Region II	—	—	—	—
Region III	0.8333	0.2719	0.7265	0.7059
Region IV	0.6330	0.6618	—	—
H. spiniceps				
Region I	0.8747	0.7776	0.8749	0.8164
Region II	—	—	0.4454	0.7860
Region III	0.8579	0.4781	0.5238	0.6512
Region IV	0.7238	0.8374	0.7138	0.6439
H. ornatus				
Region I	0.7091	0.6437	0.6806	0.7266
Region II	—	—	0.4602	0.5123
Region III	0.5599	0.4601	0.7230	0.7474
Region IV	0.6475	0.9264	0.7224	0.9211
H. oxycephalus				
Region I	0.5178	0.3399	—	—
Region II	—	—	—	—
Region III	0.6515	0.2223	—	—
Region IV	0.6780	0.5410	—	—
H. acutifrons				
Region I	0.7046	0.5539	0.5264	0.7144
Region II	—	—	—	—
Region III	—	—	—	—
Region IV	—	—	0.9065	0.7553
H. austini				
Region I	0.6363	0.5113	0.3760	0.5689
Region II	—	—	—	—
Region III	—	—	0.6277	0.2698
Region IV	0.5000	0.3597	—	—
H. mucronatus				
Region I	0.9375	0.4337	0.7095	0.9658
Region II	—	—	—	—
Region III	—	—	—	—
Region IV	—	—	—	—

Region: I, Arabian Sea; II, Bay of Bengal; III, SW Indian Ocean; IV, SE Indian Ocean.

Table 1 gives the comparison of day and night collections, in different region for 8 species for SW and NE monsoons. For *H. longicornis*, there is no significant difference between day and night collections in different regions in both seasons. For *H. paralongicirrus* southwest Indian Ocean shows a significant difference between day and night collections at 5% level in SW monsoon period and the number of specimens in night collections are more compared to day collections. For *H. spiniceps* there is no significant difference between day and night collections in both seasons. *H. ornatus* shows a significant difference between day and night collections in Bay of Bengal in SW monsoon at 5%

level. Number of specimens in day collections are more compared to the night collections. In *H. oxycephalus* a significant difference can be noticed between day and night in southwest Indian Ocean in SW monsoon at 5% level. Number of specimens are more in night than in day. There is no significant difference for species *H. acutifrons*, *H. austini* and *H. mucronatus*.

Comparisons of regions irrespective of seasonal and diurnal variations for each species indicate that *H. longicornis* shows no significant result. In *H. paralongicirrus* significant difference is noticed between Arabian Sea and southwest Indian Ocean and Arabian Sea and Bay of Bengal ($P < 0.01$, $P < 0.05$). Arabian Sea is having more number of specimens than southwest Indian Ocean and Bay of Bengal. *H. spiniceps* shows a significant difference ($P < 0.001$) between Arabian Sea and southwest Indian Ocean. *H. ornatus* shows a significant difference between Arabian Sea and Bay of Bengal; southeast Indian Ocean and Bay of Bengal, and southwest Indian Ocean and Bay of Bengal ($p < 0.05$, $P < 0.05$, $P < 0.01$). In all 3 cases Bay of Bengal shows more count. *H. oxycephalus*, *H. acutifrons*, *H. austini* and *H. mucronatus* show no significant difference between the regions.

Comparison of 2 seasons irrespective of diurnal and regional variations indicates that *H. longicornis* shows a significant difference between the 2 seasons ($P < 0.01$). NE monsoon shows more count compared to SW monsoon. For other species the seasonal differences are not significant.

Comparisons between seasons, regions and day and night variations for all species taken together have been made. The differences between (i) seasonal means in different regions, (ii) day and night variations in regions and seasons, (iii) day and night of all regions taken together and (iv) NE and SW monsoons collections irrespective of regional and diurnal variations are not significant.

Table 2—Station Data for Rare Species

Ship	Cruise No.	St. No.	Lat.	Long.	Date	Time (hrs)	Depth	Species	No./st. haul
Anton Bruun	4A	189	24°00′N	62°04′E	1-11-63	0311	200-0	*H. chierchiae* (f. st. IV)	2
Discovery	3	5385	11°19′N	64°32′E	22-5-64	2247	”	do	2
Anton Bruun	1	26	10°39′N	93°49′E	26-3-63	1530	”	*H. bulliceps* (f. st. IV)	1
do	5	312	31°26′S	74°57′E	12-4-64	1229	”	do	1
Koyomaru	14	23	19°58′S	94°02′E	1-1-63	1955	261-40	do	1
Umitakamaru	24	6312	21°04′S	112°50′E	11-12-63	1102	239-33	do	3
Diamentina	1/63	7	27°30′S	110°00′E	31-3-63	2115	220-25	*H. fons* (f. st. IV)	1
do	2/63	78	15°30′S	110°00′E	28-5-63	1045	210-18	*H. fons* (f. st. V)	1
do	2/63	80	18°30′S	110°00′E	29-5-63	1030	200-0	do	1
Vitiaz	36	5223	28°18′S	62°33′E	26-12-64	0910	200-0	*H. fertilis* (m. adult)	1

Table 3—Numerical Abundance and Maximum Density of Different Species of *Haloptilus* during SW and NE Monsoons

Species	SW monsoon		NE monsoon		Maximum observed density			
					SW monsoon		NE monsoon	
	Total	Av. No./st. haul	Total	Av. No./st. haul	Station No.	No./st. haul	Station No.	No./st. haul
H. longicornis	14601	69	12140	72	AB. 109	342 D	Va. 2007	632 D
H. paralongicirrus	768	8	573	8	Di. 5458B	26 D	AB. 191	25 N
H. spiniceps	943	8	730	8	Di. 5038	50 N	AB. 196	125 N
H. ornatus	676	7	513	7	AB. 323	25 D	AB. 67	39 D
H. oxycephalus	193	4	79	4	AB. 78	24 D	Me. 135	19 N
H. acutifrons	104	5	98	5	AB. 358	14 D	AB. 51	10 D
H. austini	69	3	66	3	Di. 5038	13 N	Me. 151 & Me. 93B	8 D
H. mucronatus	57	7	103	7	Ar. Lu. 43	25 N	Me. 95B	19 D

D = Day and N = Night

A total of 11 species of *Haloptilus* are recorded earlier from the Indian Ocean and 12 species from different parts of the ocean are encountered during the present study. Data concerning the stations and number of specimens for rare species are presented in Table 2. Numerical abundance and maximum density of various species during the 2 seasons are given in Table 3. Highest density of most of the species are noticed in the upwelling areas of the ocean. On the basis of the spatial distribution the species can be grouped into (1) widely distributed species—*H. longicornis;* (2) species showing preference to equatorial waters—*H. paralongicirrus* and *H. oxycephalus;* (3) species showing patchy distribution—*H. spiniceps* and *H. ornatus;* (4) species showing scattered distribution—*H. mucronatus, H. acutifrons* and *H. austini* and (5) rare species—*H. bulliceps, H. chierchiae, H. fertilis* and *H. fons.*

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Characterization of Marine Food Borne Pathogen, *Vibrio parahaemolyticus*, Isolated from Freshwater Fishes

R NATARAJAN, G BALAKRISH NAIR & MARTIN ABRAHAM
Centre of Advanced Study in Marine Biology, Annamalai University, Parangipettai 608 502

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Twelve strains isolated from freshwater fishes were identified as *V. parahaemolyticus* using a battery of morphological, cultural and biochemical tests. Characteristics of these were compared with 2 confirmed strains of *V. parahaemolyticus*, isolated from the Vellar estuary. In general, characteristics of the freshwater strains conformed to those exhibited by the estuarine strains with only minor variations and showed a percentage similarity >94.6. All the strains isolated were Kanagawa negative and thus nonpathogenic.

Reports on the incidence of *Vibrio parahaemolyticus*, a marine diarrhoeagenic human pathogen, in freshwater realms are scanty since it is a halophile requiring a moderate concentration of sodium chloride for growth and survival. Na^+ requirement of marine bacteria is a specific attribute and a prerequisite for a number of essential cellular functions[1]. For an organism exhibiting, *in vitro* and *in situ*, a mandatory requirement for sodium chloride, to be able to subsist in an environment devoid of salt is thus an oddity. Some reports[2-5], however, imply that the halophilic *V. parahaemolyticus* and other related vibrios are likely to have a wider distribution extending into freshwater realms as well.

The present study relates to the characterization of some strains of *V. parahaemolyticus* isolated from freshwater fishes. The results are compared with characteristics of 2 confirmed strains of *V. parahaemolyticus* isolated from estuarine environs at Porto Novo. Its entry into freshwater environs and probable trends towards adaptation are also discussed.

Materials and Methods

Freshwater fishes (106) were caught during December 1977-May 1978 from freshwater environs ($<1^\circ/_{oo}$ salinity) in the vicinity of Porto Novo (11°29′ N; 79°49′ E) by cast net operations. The fishes were immediately transferred to the laboratory in sterile polythene bags kept in ice bucket (4°C). Swabs of external surface, gills and faeces were transferred to tubes containing 10 ml glucose salt teepol broth. After incubation for 6 hr at 37°C, cultures from tubes were streaked on thiosulphate citrate bile salt sucrose (TCBS) agar plates and incubated at 37°C for 24 hr. On the subsequent day plates were screened for presence of 'typical' green sucrose non-fermenting colonies indicative of presumptive *V. parahaemolyticus*[6]. Representative colonies were picked at random and restreaked for purity. Single isolated colonies so obtained were maintained on salt water yeast extract agar slopes for further characterization.

Presumptive colonies were once again checked for purity and gram reaction and then subjected to a battery of cultural and biochemical tests (Table 1). Parallel tests were run for 2 confirmed strains of *V. parahaemolyticus* isolated from the Vellar estuary (Porto Novo) for comparison. Motility was examined by the hanging drop method while swarming was tested on trypticase soy agar plates containing 1 and 2% agar. Cultural characteristics were examined in trypticase soy broth (TSB) containing appropriate sodium chloride concentration and initial *p*H adjustments were made as required for the test. Growth at various temperatures was tested using TSB with 3% NaCl. Indole production, gelatin liquefaction, lysine and ornithine decarboxylase, arginine dihydrolase, Hugh-Leifson's oxidation and fermentation reaction, cytochrome oxidase, H_2S production in TSI and fermentation of 14 carbohydrates were performed[7]. Carbohydrates used were sterilized by passage through 0.45 μ membrane filter (Millipore Corp., Bedford, Mass.). Nitrate reduction and catalase production were tested as detailed by Sakazaki *et al.*[8] while starch hydrolysis was examined by employing the procedure outlined by Twedt *et al.*[9]. The method of Fujino *et al.*[10] was used for the cholera-red reaction. For the utilization of organic acids the inorganic basal medium used by Kaneko[11] was employed. Sensitivity/resistance to pteridine (0/129) and to penicillin were studied using the disc method. Observations on the Kanagawa phenomenon were made[12] using 10% human blood.

Results and Discussion

Morphological examination indicated that all 12 isolates, identified as *V. parahaemolyticus*, were short gram-negative rods exhibiting pleomorphism. Colony morphology on TCBS agar plates after 24 hr incubation showed round (approx. 2-3 mm diam.) green (with a slight bluish tinge), translucent colonies with elevated dark spotted centres and entire edges. All strains exhibited motility. Nine strains swarmed on 1% agar plates although the degree of spreading was relatively less compared to the prolific swarming of *V. alginolyticus*. Ability of some strains of *V. parahaemolyticus* to swarm on 1% agar plates has already been reported[8,9]. None of the strains, however, swarmed on 2% agar plates. Cultural characteristics of all strains in various sodium chloride concentrations and *p*H and temperature ranges showed typical *V. paranaemolyticus* response except for one which did not grow in 8% NaCl. Four strains showed pellicle formation in broth media which settled to the bottom on shaking. Formation of pellicle by certain cultures of *V. parahaemolyticus* was reported[8,13]. Biochemically all strains isolated in the present study showed a gross similarity to the general characteristics of *V. parahaemolyticus*. All strains were sensitive to pteridine (0/129) and resistant to penicillin. None of the strains showed a positive betahaemolytic reaction on Wagatsuma's blood agar and was therefore considered apathogenic. Responses of all strains as compared to estuarine strains are presented in Table 1.

Characteristics of isolates from freshwater fishes which were different from those exhibited by estuarine strains of *V. parahaemolyticus* are presented in Table 2.

Table 1—Morphological, Cultural and Biochemical Response of *V. parahaemolyitcus* Isolated from Freshwater Fishes in Comparison with Estuarine Strains

Trait	Composite response of 2 estuarine strains	Response (12) +	Response (12) –
Morphological			
Gram stain	–	0	12
Motility	+	12	0
Swarming			
1% agar	+	9	3
2% agar	–	0	12
Cultural			
Growth at			
4°C	–	0	12
25°C	+	12	0
37°C	+	12	0
42°C	+	12	0
*p*H 5	+	12	0
*p*H 6	+	12	0
*p*H 7	+	12	0
*p*H 8	+	12	0
*p*H 9	+	12	0
Growth in NaCl (%)			
0	–	0	12
0.5	+	12	0
1	+	12	0
3	+	12	0
5	+	12	0
8	+	11	1
10	–	0	12
Biochemical			
Indole	+	12	0
Nitrate reduction	+	12	0
Gelatin liquefaction	+	12	0
L-Lysine decarboxylase	+	12	0
L-Ornithine decarboxylase	+	12	0
L-Arginine dihydrolase	–	0	12
Cholera-red reaction	+	9	3
Gas from glucose	–	0	12
Biochemical			
Oxidation and fermentation (f) of glucose	+ (f)	12 (fermentative)	0
Catalase production	+	12	0
Cytochrome oxidase	+	12	0
H_2S Production (TSI)	–	0	12
Starch hydrolysis	+	12	0
Methyl red	+	12	0
Voges-proskauer	–	0	12
Fermentation of			
Glucose	+	12	0
Sorbitol	–	0	12
Rhamnose	–	1	11
Mannitol	+	12	0
Lactose	–	1	11
Maltose	+	12	0
Dulcitol	–	0	12
Arabinose	+	10	2
Xylose	–	0	12
Sucrose	–	0	12
Salicin	–	1	11
Adonitol	–	0	12
Inositol	–	0	12
Trehalose	+	12	0
Utilization of			
Acetic acid	+	10	2
Oxalic acid	–	0	12
Lactic acid	+	9	3
Malic acid	+	9	3
Antibiotic sensitivity			
Pteridine 0/129	+	12	0
Penicillin (10 units)	–	0	12
Kanagawa phenomenon	–	0	12

Table 2—Traits of Freshwater Isolates Which Differed from Those Exhibited by Estuarine Strains of *V. parahaemolyticus* and Percentage Similarity

Strain No.	Trait										Percentage variation	Percentage similarity (100—percentage variation)
				Fermentation of				Utilization of				
	Swarming (1% agar)	Growth in 8% NaCl	Cholera-red reaction	Rhamnose	Lactose	Arabinose	Salicin	Acetic acid	Lactic acid	Malic acid		
1	+								+		3.6	96.4
2			+							+	3.6	96.4
3			+						+		3.6	96.4
4			+					+			3.6	96.4
5								+			1.8	98.2
6		+							+		3.6	96.4
7							+				1.8	98.2
8						+					1.8	98.2
9	+										1.8	98.2
10	+									+	3.6	96.4
11						+					1.8	98.2
12				+	+					+	5.4	94.6
Total	3	1	3	1	1	2	1	2	3	3		

+ = Trait variation

Percentage similarity of the 12 strains characterized in the present study to the confirmed estuarine strains of *V. parahaemolyticus* was very high (>94.6%). Twedt *et al.*[9] reported that many strains of *V. parahaemolyticus* from Japan and USA exhibited a positive cholera-red reaction as found in the present study, but others[8,14] found a negative reaction in most of the cultures studied. Strains isolated in the present investigation showed some variations (Table 2) but such intraspecific variations among strains of *V. parahaemolyticus* were also reported by earlier investigators[9,13,15]. As stated by Skerman[16], 100% similarity between any 2 strains subjected to larger number of tests appears to be a rarity.

All the 12 strains did not grow in TSB without sodium chloride. It should be pointed out here that according to Rottini *et al.*[17] marine Vibrios, including *V. parahaemolyticus*, are not homogenous regarding Na^+ requirement and its substitution with other monovalent ions. They further observed that when suitable concentration of K^+ or Li^+ were present, *V. parahaemolytics* was able to reduce its Na^+ requirement to values lower than physiological concentrations. In the light of the above findings the presence of *V. parahaemolyticus* in freshwater environs cannot be excluded.

V. parahaemolyticus was detected in all the genera (*Clarius*, *Mystus*, *Anabas* and *Catla*) except in *Labeo*. Overall percentage of occurrence was however low (11.3%). Highest frequency of occurrence was in the genus *Catla*. Among the 12 isolates identified as *V. parahaemolyticus*, 10 were isolated from faeces while only 2 were isolated from the external surface of fish. Preponderance in faecal samples of fishes indicates the organism's preference for an enteric habitat. A rich nutrient store is available in the gut of fishes[18] probably affording a suitable niche for the proliferation of the pathogen.

Presence of *V. parahaemolyticus* in tropical and temperate, estuarine and nearshore coastal waters has been recorded[6,11,19-22]. Chatterjee and Neogy[2] first reported isolation of *V. parahaemolyticus* from nonmarine fishes. De *et al.*[23] reported that 40, 30, 25 and 16.7% respectively of pond, river, sewage and tap waters were positive for *V. parahaemolyticus*. They further indicated that 13% of the freshwater fishes sampled were contaminated with this pathogen. The present study indicates a slightly lower percentage of occurrence (11.3%) of *V. parahaemolyticus* in freshwater fishes from Porto Novo. Studies at the Cholera Research Centre[4,5] have revealed the occurrence of this pathogen in flies, cooked food, open wells, ponds and stored water. All reports on the occurrence of *V. parahaemolyticus* from freshwater sources have been only from Indian waters. In India, majority of the human population are in greater and continuous contact with all types of water bodies (rivers, estuaries and tanks) in one way or other and obviously such practices might have resulted in the introduction of this pathogen into these environs through infected and subclinical cases.

Employing the rRNA homology technique, Baumann and Baumann[24] found that the freshwater diarrhoeagenic pathogen *V. cholerae* exhibited a closer relationship to marine rather than to terrestrial enterobacteria suggesting its possible marine origin.

They speculated that selection pressures leading to the establishment and dissemination of a successful pathogen may have resulted in the gradual loss of its original Na^+ requirement leading to the evolution of an accidental marine pathogen into a successful human intestinal pathogen. It is reasonable to assume that *V. parahaemolyticus* may be evolving this way from marine to a freshwater habitat to get established successfully as a potential human enteric pathogen. The emergence of *V. parahaemolyticus* in freshwater environs, apart from adding to the existing spectrum of pathogenic limnic bacterial species, will further accentuate the public health hazard. It is imperative, therefore, to undertake a more serious and detailed study of this pathogen collected from all sources.

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Microbial Decomposition of the Floating Weed *Salvinia molesta* Aublet in Cochin Backwaters

E V RADHAKRISHNAN*, P S GORE, O RAVEENDRAN & R V UNNITHAN
National Institute of Oceanography, Regional Centre, Cochin 682018

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From the live and decomposing *S. molesta* 13 strains of bacteria were isolated and the growth promoting effect of the weed extract in various concentrations on 5 selected strains of bacteria and a mixed culture was studied. Turbidity measurements gave maximum percentage transmission in 5% extract. Dry weight loss of dried weed in the laboratory was 20 and 25% after 10 and 25 days of incubation respectively. Yield efficiency of 3 bacterial strains calculated for 48 hr was 20%. The results suggest the potential value of this primary source of organic material in the food web of Cochin backwaters.

Nutritional significance of detritus along with associated micro-organisms in estuarine ecosystem has been studied[1-6]. The Cochin backwater system receives allochthonous organic matter, primarily from the floating weed *Salvinia molesta* during monsoon.

There is no information on the microbial association and detritus formation from the weed in Cochin backwaters though some information is available on the animal association[7] and seasonal fluctuation and chemical characteristics[8] of detritus in the backwaters. Present study attempts to understand (i) utilisation of soluble weed components by aerobic, heterotrophic bacteria, isolated from fresh as well as decomposing weed in the backwaters, (ii) microbial decomposition of dried weed in the laboratory and (iii) yield efficiency (conversion of low protein weed biomass into bacterial protoplasm) of selected strains of bacteria.

Materials and Methods

Fresh and decomposing *S. molesta* from backwaters was collected (September and October 1975) in sterile glass containers and carried to the laboratory in iced condition. The weed (5-10 g) was aseptically chopped into fine pieces and enumeration of viable counts carried out on the suitably diluted samples using sea water agar (SWA) and freshwater agar (FWA) media by the pour plate methods. Morphological and biochemical tests were performed[9]. Large samples of the fresh weed were also collected from the same area to prepare weed extracts of desired concentrations[10] (0.5, 1, 5 and 10%) to study the growth promoting effect on selected strains of bacteria. Millipore filtered extract was dispensed (20 ml/100 ml conical flask) and sterilised at 15 lb pressure for 15 min. The generic classification of 13 strains of aerobic, heterotrophic bacteria was done as per the modified scheme of Simidu and Aiso[11]. Morphological and biochemical characteristics of the isolates are given in Tables 1 and 2.

Each of the 13 isolates maintained on sea water agar slant were tested for their ability to grow in 5% weed extract broth. Growth of 5 isolates (E_1 *Serratium*, E_2 *Flavobacterium*, E_3 an unidentified gram negative yellow cocci, 8 *Pseudomonas* and 13 *Bacillus*) and a mixed culture of bacteria (MC), in different concentrations of sterilised weed extract (0.5, 1, 5 and 10%) was studied at 28±2°C (Fig. 1). The extracts inoculated with the bacterial isolates were incubated for 48 hr in a waterbath shaker. Growth response after 48 hr incubation was measured at 620 nm in a 'Specometer' with corrections to exclude absorption by the pale brown weed extract (Fig. 1). To study variations in growth between the strains and between concentrations of the extract the results were subjected to analysis of variance.

Loss in dry weight of dried weed in the laboratory due to microbial activity was studied[10]. For estimating conversion of weed into microbial biomass, 3 strains of bacteria (E_1 *Serratium*, 8 *Pseudomonas* and 13 *Bacillus*) were allowed to grow in 3 different concentrations (0.5, 1 and 1.5%) of weed extract prepared in sea water. Weed extract dispensed (20 ml) into conical flasks was sterilised and inoculated with 2 ml of actively growing nutrient broth culture. Turbidity was measured using a Specometer (Elico model: C4-21). After 48 hr incubation dry weight of bacteria was estimated by the filtration method[10]. The values for dry weight of 3 cultures determined at each level of weed extract are presented in Fig. 2. In this

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*Present address: Madras Research Centre of CMFRI, 29 Commander-in-Chief Road, Egmore, Madras 600008.

Table 1—Morphological and Growth Characteristics

Strain No.	Description of colony on SWA	Growth		
		Nutrient broth	SWA slant	FWA
1	Round, surface, convex, rose coloured colony	Uniform turbidity, thin pellicle at top	Filiform, dry growth	No visible growth
2	Round, surface, white colony with complete margin	Medium turbid, no pellicle	Filiform	do
3	Round, surface, cream coloured colony with complete margin	Medium turbid, membraneous pellicle at top	do	Poor growth
4	Horse-shoe shaped, surface white colony with lobated margin	Uniform turbidity, no pellicle	do	—
5	Round, surface, pale yellow colony	Medium turbid, no pellicle	do	Luxuriant growth
7	Round, sub-surface, white colony with smooth surface	Uniform turbidity, thin pellicle at top	do	No growth
8	Oval shaped, sub-surface white colony with frilled margin	Uniform turbidity thin pellicle	do	Poor growth
9	Round, surface, white colony	Uniform turbidity, no pellicle	do	Fair growth
10	Round, sub-surface small white colony with metallic shining	Uniform turbidity	do	No growth
11	Round, surface, small, white colony	Uniform turbidity thin pellicle at top	do	Poor growth
13	Round, white, sub-surface, feather margined colony	Uniform turbidity, no pellicle	Filiform luxuriant growth	Thick luxuriant growth
14	Oval, cream coloured, surface colony with frilled margin	Uniform turbidity, no pellicle	Filiform	Poor growth
15	Oval, pale yellow, surface colony	Uniform turbidity	do	do
E-1	Oval, red surface colony	do	do	Good growth

Other morphological characteristics:

Motility : All strains motile except 10 and 11 which were passive
Growth at *p*H 6 : All showed good growth except strain 1 which showed satisfactory growth with turbidity
Pigmentation : Strain 1, rose-pink; strain 5, yellow; and strain E-1, red
Irridescence : Strains 2 and 3, greenish and strains 8, 11 and 14, bluish

experiment the number of bacteria per ml determined by dilution and plating after 48 hr in the medium containing 500 mg of extract per 100 ml was isolate E_1, 1.03×10^8; isolate 8, 1.64×10^8 and isolate 13, 2.06×10^8.

Results and Discussion

Growth response in 5% weed extract broth indicated that 8 bacterial isolates (strain Nos. 1, 3, 4, 5, 8, 10, 13 and 15) grew well in the extract while the rest exhibited slight growth. When all the isolates were tested for their ability to grow in standard nutrient broth and sea water broth, only 3 (strains 5, 9 and 13) showed appreciable growth in standard nutrient broth, 4 showed no growth and 5 showed poor growth (Table 1). All isolates showed appreciable growth in sea water broth. Of the isolates 50% grew better in weed extract medium than in sea water nutrient broth indicating the bacterial growth promoting factor of the weed. Many of the isolates appeared to be marine bacteria with respect to their requirements of salinity for their growth[12].

The growth promoting activity of the soluble components of the weed is clearly evident from the experiment. Data were analysed using analysis of variance. For framing the analysis of variance, the percentage transmission data were converted to angles using angular transformation, in order to stabilise the variance. There was significant ($P < 0.01$) variation between percentage transmission values. The variation between strains was not significant at 5% level. The least significant difference (LSD) at 5% level was formed and the mean of percentage transmission compared. Percentage transmission in 5% was highest compared to percentage transmission in 0.5 and 1%. The percentage transmission in 10% was less than that of 0.5%.

The percentage loss of organic matter during the initial 10 days of incubation was 20% whereas only 5% decomposition was noticed in the next 15 days. The initial loss of 20% may be attributed to the ready decomposition of protein and other soluble extractives, which were estimated[13] to be 42%. These components are easily susceptible to microbial attack.

Table 2—Biochemical Characteristics

Strain No.	Hugh & Leifson's Test	Fermentation of sugars (sucrose, glucose, maltose, mannitol and lactose)	Gram staining	Bacteria
1	NF	Nil	(−)ve elongated rods	*Pseudomonas* sp.
2	FNG	All except lactose	(−)ve short rods	*Vibrio* sp.*
3	NF	Nil	(−)ve elongated rods	*Pseudomonas* sp.
4	do	Nil	do	*Pseudomonas* sp.
5	FNG	All except lactose	(+)ve rods with central spores	*Bacillus* sp.*
7	NF	Nil	(−)ve elongated rods	*Pseudomonas* sp.
8	do	Nil	(−)ve short rods	*Pseudomonas* sp.
9	do	Nil	(−)ve elongated rods	*Achromobacter* sp.*
10	do	Nil	do	*Pseudomonas* sp.*
11	do	Nil	(−)ve short rods	*Pseudomonas* sp.
13	FNG	All except lactose	(+)ve spore-forming rods with central spores	*Bacillus* sp.
14	NF	Nil	(−)ve short rods	*Achromobacter* sp.
15	do	Nil	(−)ve elongated rods	*Achromobacter* sp.
E-1	do	All except maltose & lactose	(−)ve short rods	*Serratium* sp.

NF = non-fermentative and FNG = fermentative, no gas
*Denitrifier

Other biochemical characteristics:

Indole production : Strain No. 2 positive; rest all negative
VP reaction : Strain Nos. 5, 13, and E-1 positive, rest all negative
Gelatin-liquefaction : Eight strains (1, 2, 5, 9, 13, 14, 15 and E-1) positive; rest negative
Nitrate reduction : All strains positive
Starch digestion : Six strains (1, 2, 9, 13, 14 and E-1) positive; rest negative
Sensitivity towards penicillin : Five strains (5, 9, 13, 14 and E-1) only sensitive

The remaining 5% loss may be due to the slow decomposition of more complex fractions such as cellulose and hemicellulose (27% of the dry weight)[14], which are less susceptible to microbial attack.

The yield efficiency for the isolates E_1, 8 and 13 for 48 hr is 20%. This is comparable to the yield obtained for salt marsh grass[10] for 48 hr incubation. According to Gosselink and Kirby[15] yield efficiency calculated for 48 hr may not reflect the maximum bacterial biomass that has been achieved during the period. They have further shown that yield efficiency can be reached even up to 46% for a longer time interval as decomposition of more refractory fractions were expected within that period.

Burkholder and Bornsby[10] assumed that 11.2% of the annual crop of marsh grass may be available for rapid production of bacterial biomass if 20% of the soluble extractives and protein is readily converted. Using the same relationship it may also be assumed that 8.4% of the weed will be available for bacterial biomass production in Cochin backwater system also ($0.42 \times 0.2 = 0.084$, i.e. 8.4%).

Role of allochthonous organic matter as a major energy source in salt marsh ecosystems and streams have been well emphasised[3,6]. According to Tait[16] in detritus based ecosystem, some of the energy is directly available to the benthic fauna by digestion and assimilation of detritus, but many detritic materials

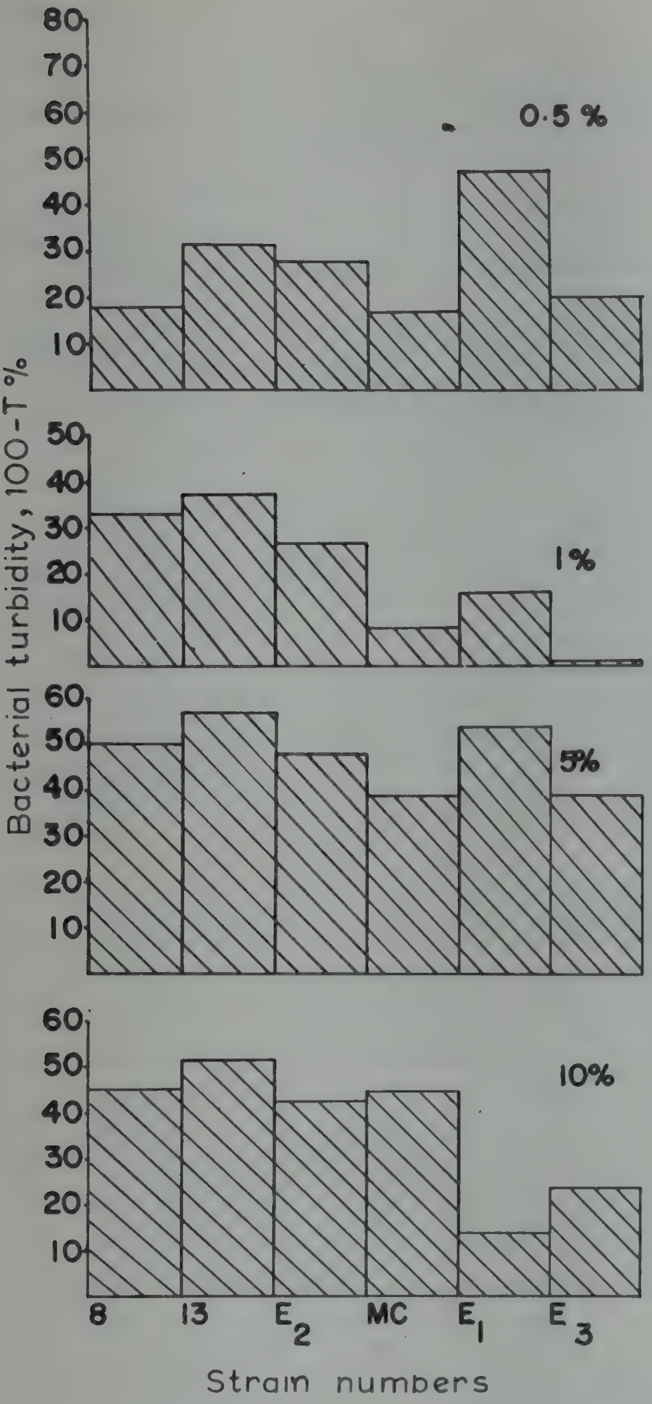

Fig. 1—Growth of 6 bacterial isolates in different concentrations of weed extract in sea water

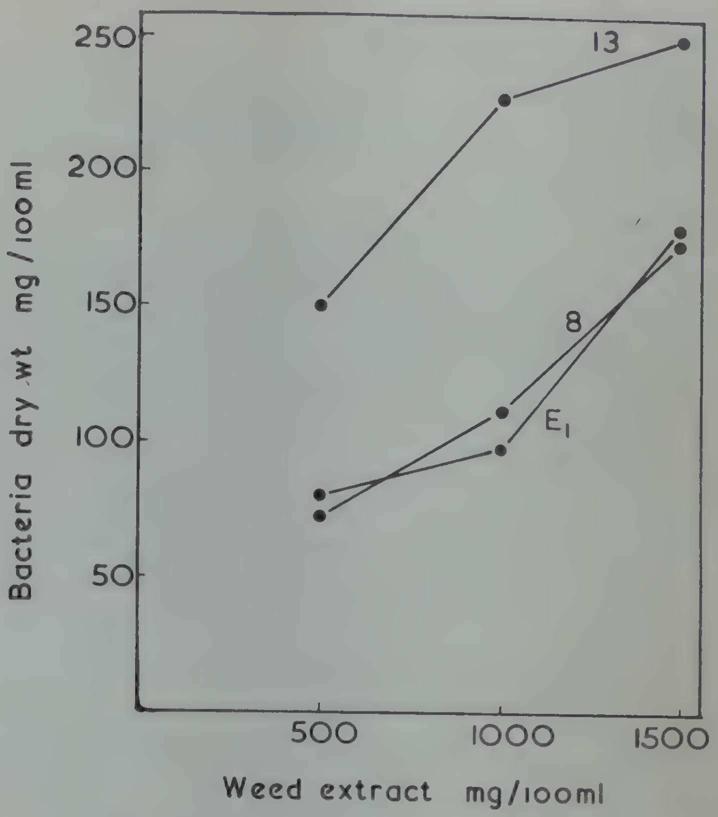

Fig. 2—Dry weight of bacterial culture grown in different weed extract concentrations

reaching the bottom cannot be digested by animals. From the experimental evidence available he further assumed that 25% of the energy intake of the benthic herbivores come directly from detritus and 75% from the consumption of associated bacteria. From the present study it is seen that *Salvinia* detritus of Cochin estuary is acted upon by bacteria which may contribute to a significant proportion of the food of benthic animals in the estuary.

Detailed studies of energy flow in natural ecosystems are available[3,17,18]. But studies of the energetics of a tropical estuarine ecosystem like Cochin backwater system are limited. From the studies of organic production and the food chain of Cochin backwaters[8,19] it is known that a major portion of energy in the form of detritus is available. The detritus constitutes an additional pathway between organic production and animal nutrition increasing the efficiency of energy transfer from one trophic level to other. The production of *Salvinia* detritus is seasonal in that the fresh weeds come to the estuarine system in monsoon months, and undergo decomposition leaving the detritus, which accumulates in the bottom. If a large proportion of detritus exists in the sediments then even a slow rate of decomposition would be sufficient, to support the consumer populations. Fenchal[6] has stated that the existence of a large quantity of slowly decomposing plant body may enable the ecosystem to continue functioning even when the primary producers are temporarily removed. Similarly the existence of decomposing *Salvinia* to some extent may prove beneficial, especially in the absence of other primary producers.

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Short Communications

Iron Precipitation in Estuarine Environment

A N SUBRAMANIAN, V RAMADHAS & V K VENUGOPALAN
Centre of Advanced Study in Marine Biology
Annamalai University, Porto Novo 608 502

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Total particulate iron concentration varied from 1336.125 to 350.012 μg/litre and total organic particulate iron concentration from 1099.44 to 290.511 μg/litre in the salinity range 6.8 to 30‰ in the Vellar estuary. Maximum (335.94 μg/litre) and minimum (59.501 μg/litre) of HCl reactive iron were observed at 0.1 and 30‰ salinities respectively. The relationship between the rate of iron precipitation and salinity was non-linear. The study revealed that (i) inorganic fraction of particulate iron could contribute only lower percentages to total particulate iron (av, 18.8%) and (ii) the role of sedimentary particles could not be neglected while considering precipitation of iron in estuaries.

Studies on the heavy metal iron gathered much interest owing to conflicting findings regarding the non-conservative behaviour of this element in transient zones like estuaries. On the basis of laboratory experiments it was reported that the whole of soluble iron brought by river water gets precipitated completely in the estuary due to sudden increase in salinity of the water[1,2]. Aston and Chester[3] showed that besides salinity, suspended sediments are also essential in enhancing the rate and extent of iron precipitation. Kamat and Sankaranarayanan[4] observed considerable decrease in particulate iron concentration from the river mouth towards offshore and they related this decrease to flocculation and settling. Holliday and Liss[5] indicated that under low salinity conditions (< 15‰) soluble iron behaves like a non-conservative element whereas at higher salinities (> 15‰) it behaves like a conservative element. The above mentioned studies were made by analysing either the reactant (soluble iron) or the product (particulate iron) under laboratory conditions.

This paper deals with *in situ* study conducted in the Vellar estuary during December 1977 and presents some information regarding precipitation of iron in estuaries. It is assumed that freshly formed particulate iron through precipitation and flocculation is in the form of either small or intermediate sized particles and would take much time to leave the surface water. Because of this limitation, only an approximate measure of the actual concentration can be given, and this provides better understanding of the pattern of precipitation over a wide range of salinities.

Surface water samples were collected by clean plastic buckets from Vellar estuary, starting from the freshwater zone and ending in the mouth of the estuary, a distance of 5 km. Only surface samples were used, since in shallow waters tidal currents would agitate the bottom (tidal range 70 cm), leading to resuspension of bottom sediments in the water. During the study period the depth of the estuary was comparatively higher (> 5 m). Immediately after the collection the samples for iron determination were preserved in clean polyethylene containers adding few milligrams of mercuric chloride. Samples without mercuric chloride were used for salinity determination[6]. Frequency of sampling for low salinity (< 10‰) sample was 18 and for high salinity (> 10‰) was 8. Particulate matter was collected by filtering a known volume of sample through Whatman glass filters (GF/C) and the filters along with particulate matter were treated with 40% hot hydrochloric acid to leach out ferric iron in the particulate matter[6]. After cooling to room temperature, the contents were filtered through a glass filter and the filter with particulate organic iron was digested with perchloric acid. HCl extractable and organic particulate fractions of iron were estimated separately after removing the residues by centrifugation, adopting the bipyridyl method[6]. Total particulate iron was calculated by adding the HCl extractable and particulate organic fractions. The precision of the method is ± 0.67 μg/litre on 1 litre sample.

Variations of total particulate and HCl reactive particulate iron with salinity are shown in Fig. 1. During the early mixing process in the estuary heavy precipitation of iron occurred. The extent of precipitation increased steadily from 0 to 6‰ salinity and decreased afterwards. Between 14 and 26‰ there was not much variation in the concentration of total particulate iron. After 26‰ it declined to reach the low value observed for the coastal water.

Since it was stressed by Sholkovitz[2] and Holliday and Liss[5] that precipitation would complete within the salinity range 0 to 20‰, frequency of sampling was increased only for the low salinity samples. The observed decrease in total particulate iron above 6‰ salinity indicated that though precipitation would occur at higher salinities also, the rate of precipitation would generally be low. This might be attributed partly to the decrease in the proportion of freshwater to sea water at higher salinity levels and the consequent

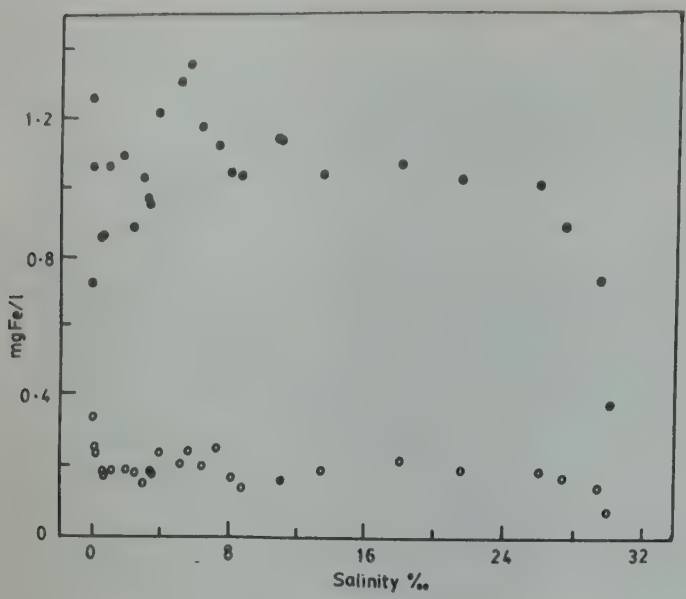

Fig. 1—Variation of HCl reactive (o) and total particulate (●) iron with salinity

decrease in concentration of soluble iron available for precipitation. Holliday and Liss[5] also indicated that precipitation of iron up to a salinity of 6‰ would be high and thereafter the rate of precipitation would decrease with further increase in salinity thereby altering the pattern of precipitation. From the present observation it can also be assumed that the relationship between the rate of iron precipitation and salinity is non-linear. Similar non-linear relationship between iron and salinity was observed earlier[2,4].

Conflicting reports exist regarding the formation of particulate iron in estuarine environments[1-3,5]. In view of this particulate iron was studied separately as inorganic and organic fraction in the present study. The HCl reactive fraction mostly represented the ferric fraction available as phosphate and anhydrous oxides of iron. It would be interesting to note that such inorganic fraction of particulate iron contributed only a low percentage (13.59- 26.85%; av. 18.81%) to total particulate iron. Because of this fact variations in total particulate iron resembled those of organic fraction. Absence of a well defined pattern in the distribution of HCl reactive fraction throughout the salinity range studied was obvious in the present study. As the concentration of this fraction could be very much affected by phytoplankters through biological utilization[7,8], such variations are bound to occur in estuaries. Since the HCl reactive iron contributes only lower percentages of the total particulate iron such variations are not prominent when compared to organic particulate iron. Further, as far as this fraction of particulate iron was concerned, besides salinity the availability of suspended sediments in the water also seemed to be more important. Suspended particles are important in the aqueous geochemistry of iron and this element is known to occur both as oxide coatings on the surface of minerals such as clays and also as discrete hydrated iron oxide particles. In the present study, differences in the concentration of total particulate iron were observed at times, even between samples of more or less the same salinity, but with varying particulate matter concentrations. The present results suggest that in studies of iron precipitation under laboratory conditions only natural samples should be employed giving importance to both salinity conditions and available suspended sediments.

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Organic Matter in Sediments Off Northeastern Andamans*

M RAMA MURTY, K V VENKATESH &
C V L NARASIMHAM
Geological Survey of India, 4, Chowringhee Lane, Calcutta 700 016

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Organic matter has been determined from 24 surficial sediment samples (from 20 to 500 m depth) collected in the offshore area between Port Cornwallis and Port Blair off Andaman Islands. Wide variation is seen in the organic matter content (0.35 to 3.58%), and the nearshore sediments are characterised by a low content of organic matter (0.35 to 1.88%) than the deeper slope sediments (2.64 to 3.58%). Areal variation of organic matter has been discussed in relation to organic and inorganic materials, prevailing hydrographical conditions, texture of sediments and other factors.

Although organic matter is rarely a major constituent in bottom sediments of the nearshore or offshore areas, it is often a good index of the environment in which the sediments are deposited. Studies of the organic matter of recent marine sediments are of interest especially for their bearing on diagenesis. There is a need to know the composition of organic matter and the conditions under which it accumulates, since the understanding of the connection between the benthos and the amount and composition of organic matter would enhance our understanding of the distribution of living organisms in the seas of geological past. Discovery of liquid hydrocarbons in recent marine sediments has demonstrated that the main components of petroleum are already present in the sediments at the earliest stages of diagenesis.

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While some data are available on the distribution of organic matter in the marine sediments of Bay of Bengal and Arabian Sea[1,2], no information is available on the organic content of sediments off Andamans. This paper presents areal variation of organic matter in sediments off Northeastern Andamans and the factors responsible for its distribution in the sediments.

Surficial sediment samples from the shelf and slope areas of Andamans were collected on board *INS Investigator* in 1971, using a van Veen grab sampler. Out of 44 samples collected in the offshore area, 24 samples were selected for the study (Fig. 1). The area of sampling was covered by the admiralty Chart No. 825. The sampling stations were located with the help of sextant bearings and by dead reckoning. According to Venkatesh[3], the sediments of the area comprised sand, sandy silt, silty sand and clayey silt. Variation in the type of sediment with depth was noticed. An admixture of sediments (sandy silt, silty sand, etc.) was found down to 50 m, beyond which mostly sand was found down to 100 m. This was followed by sandy silt and clay down to 500 m.

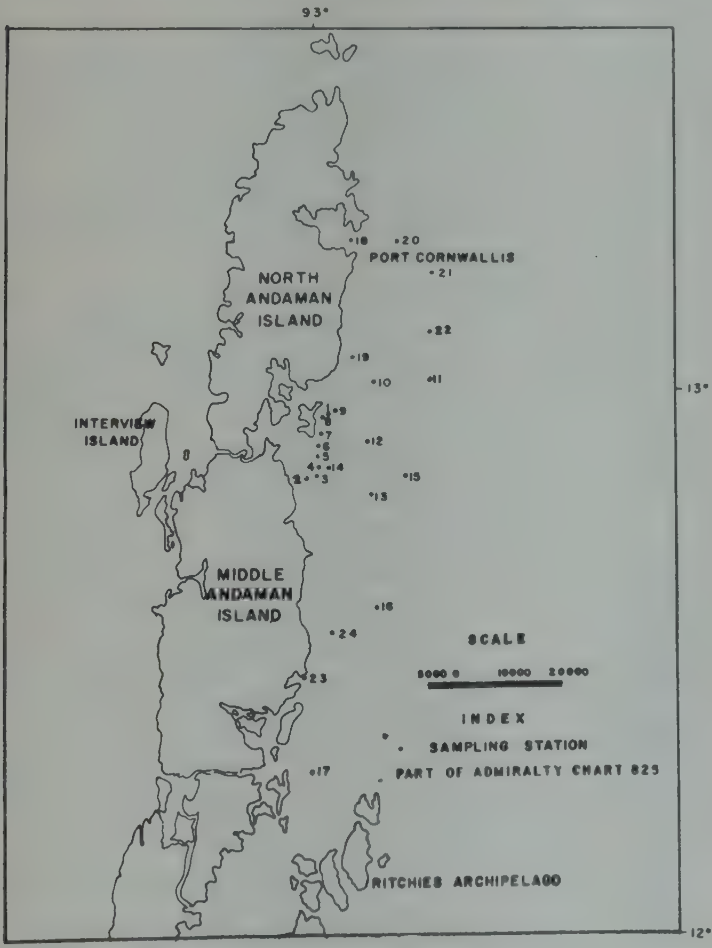

Fig. 1—Sample locations

Organic carbon was determined by the titration method of Walkley and Black[4] as modified by Jackson[5]. Organic matter was computed by multiplying with a factor of 1.724, corresponding to 58 % carbon in soil organic matter, as recommended[6].

Organic content in the sediments is given in Table 1. Areal variation of organic matter is shown in Fig. 2.

There is a wide variation in the organic content (0.35 to 3.58 %). On an average, the percentage of organic matter is 1.73 which is below the world average of 2.5 % for nearshore sediments[7]. However, this value is higher than the average of 1.33 % for the marine sediments off east coast of India[1] and is lower than the 2.55 % for marine sediments off west coast of India[2].

The nearshore sediments have low organic content than the deeper offshore sediments (Fig. 3A). As to the relationship between texture and organic content, fine grained sediments have higher content than coarse grained ones (Figs 3B and C).

A number of factors are responsible for the accumulation of organic matter in marine sediments. The important among them are (i) supply of organic material to the environment of deposition through surface waters, (ii) rate of deposition of organic material, (iii) rate of decomposition of organic substances, and (iv) texture of sediments. The ultimate source of organic matter that is buried in sediments is some form of plant life and phytoplankton[8,9]. It is believed that the deposition of organic matter in the nearshore sediments off northeastern Andamans close to the land mass might have been contributed by the plant material of terrigenous origin through the overlying waters. But, the nearshore sediments are not so rich in organic content as those of the deep offshore area, despite additional supplies of organic materials from the islands brought by numerous streams. This may be explained by the relative rates of deposition of organic and inorganic materials as the low organic content of these sediments seems to be due to rapid rate of deposition of coarser inorganic constituents (clastic sediments) in relation to organic material. Oxidising waters of the nearshore[10] have favoured the destruction of organic production due to intense oxidation processes. Oxygen liberated due to photosynthetic activity of planktonic organisms in the euphotic zone, which extends down to the bottom nearshore has also perhaps expedited the destruction of organic matter while still in suspension. Thus, high rate of decomposition of organic matter in the nearshore zone clearly explains the low values of organic matter. Emery[11] points out that water temperature is an important factor determining the degree of accumulation of organic matter. Ramesh Babu and Sastry[10] have reported relatively higher temperatures in the nearshore waters than the deeper

Table 1—Organic Content in Sediment Samples

St No.	Depth m	Nature of samples	Mean size of sediment	Percentage of Clay	Percentage of Organic matter	Percentage of $CaCO_3$
1	52	F	—	—	1.88	—
2	34	A	4.04	5.5	1.88	7.92
3	97	A	2.5	4.79	1.41	33.18
4	90	A	3.16	7.02	2.35	30.69
5	72	A	3.34	4.3	0.98	20.79
6	53	A	3.29	5.94	0.77	14.4
7	55	A	4.19	7.36	1.21	10.98
8	62	A	3.69	9.24	1.19	9.72
9	110	A	2.31	7.08	0.61	17.73
10	264	C	5.5	15.5	1.55	23.04
11	484	E	4.28	12.26	1.84	44.87
12	408	B	—	—	2.27	—
13	390	C	4.86	10.71	3.58	28.44
14	154	B	—	—	3.07	—
15	508	B	—	—	3.3	—
16	284	B	—	—	2.05	—
17	43	B	—	—	1.6	—
18	36	C	5.54	12.88	1.51	26.01
19	252	B	—	—	1.97	—
20	104	C	4.72	8.93	1.55	19.08
21	488	D	—	—	1.64	—
22	480	B	5.49	14.53	2.59	44.37
23	24	B	7.02	28.14	2.95	5.4
24	64	D	—	—	0.35	—

A = sand; B = clay; C = sandy silt; D = clayey sand; E = silty sand; and F = sandy clay

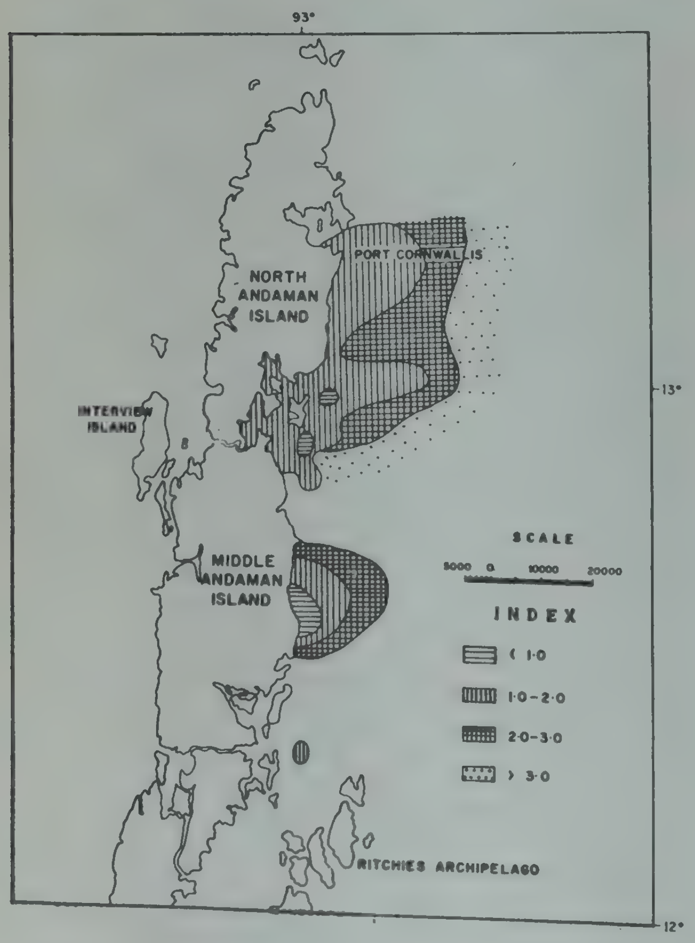

Fig. 2—Areal variation of organic matter in sediments

slope region. These high temperature waters might have actively decomposed the organic matter in the nearshore zone, thereby reducing its content of accumulation. Finally the low content of organic matter in the nearshore sediments is due to the presence of coarser sediments like sands, sandy silts, and clayey sands.

In addition to the supply from the terrigenous plant materials, the relatively high content of organic matter in sediments of the deeper offshore areas is attributed to the cumulative result of factors, viz. (i) high organic production from the abundant planktonic material, (ii) availability of low oxygen in the environment, and (iii) presence of fine clay sediments. Coarse fraction studies[12] reveal the presence of shells in abundance of planktonic foraminifera such as *Globigerina* and *Globorotalia* in the sediments of the slope area which indicate the existence of favourable conditions for the deposition of material in suspension. Further the positive correlation exhibited by calcium carbonate and organic matter (Fig. 3D) and the presence of higher concentration of calcium carbonate and organic matter in the sediments of the deeper regions strongly suggest the production of organic matter from the calcareous planktonic material. Hydrographic studies off Andamans suggest the presence of low

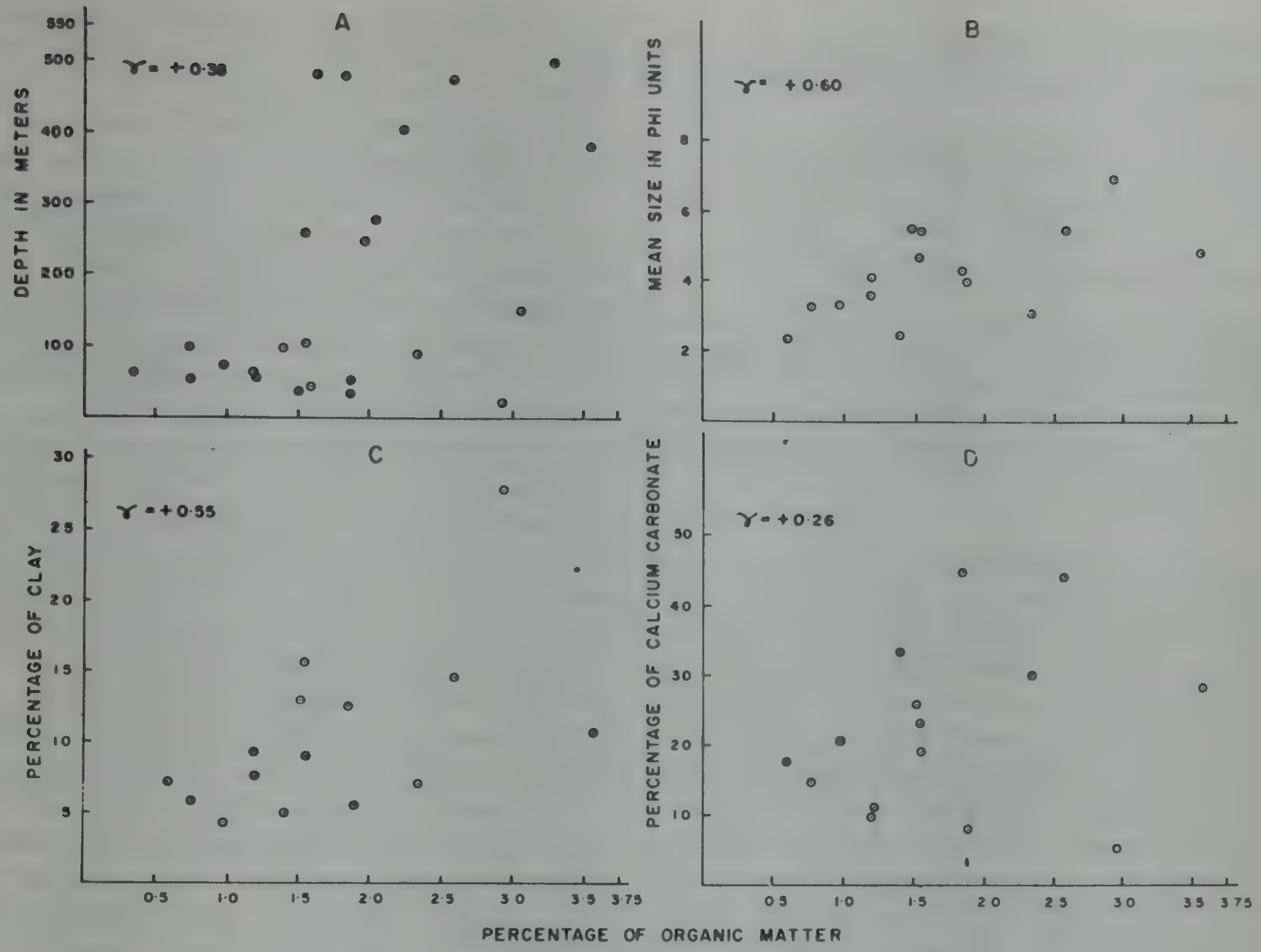

Fig. 3—Relationship of organic matter with depth (A), mean size (B), Clay (C), and Calcium Carbonate (D) in sediments

levels of oxygen in the waters of the slope region[10]. Although the rate of deposition of organic material in a sedimentary environment is controlled by several factors, it is well known that the availability of oxygen is the most important one. In reducing environments, especially those existing in the nonturbulent areas, very little decomposition of organic matter is accomplished. In view of low values of dissolved oxygen, high content of organic matter in the sediments of the slope region is due to the low rate of decomposition. The relatively deeper, less turbulent and less aerated waters in this region, where fine clayey sediments are deposited, are favourable for the accumulation of higher amount of organic matter, since organic substances which have density slightly greater than the overlying waters can accumulate in considerable quantities in quiet places. Thus, finally the high content is attributable to its finer texture.

Organic matter shows a positive correlation (Fig. 3B, $r = +0.60$) with phi mean size of the sediment suggesting that with increase of phi mean size the organic matter increases. It has been observed by a number of investigators that the fine grained sediments generally contain higher amount of organic matter than the coarser ones. The main cause for the variation in organic content with respect of texture is the similarity in settling velocity of organic constituents and fine particles[7].

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Colonization of Graded Sand by the Interstitial Fauna of Monazite Sands

K C RAJAN & N BALAKRISHNAN NAIR

Department of Aquatic Biology and Fisheries, University of Kerala, Trivandrum 695 007

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Preferences of particular groups of the psammic fauna to monazite sands are indicated. The samples of graded sand are populated by fauna which are considerably much poorer both in number and in species than that occurring either in the ungraded sand or in the fresh beach sand. A general reduction in the total number of animals in relation to a decrease in the grain size is also noted.

Characteristics of sand grains, including their shape, size, origin and composition, determine to a great extent the species, the number of organisms and the correlation between their body inhabiting the interstitial spaces[1,2]. Most of the ecological investigations carried out on the interstitial fauna have included a granulometric study and this has provided a useful guide to the characteristics of different localities.

Nair and Govindankutty[3] studied the colonization of the graded sands by the interstitial fauna in the sands of Cochin beaches. All investigations on this aspect were carried out on animals inhabiting the silicious sands. Keeping this in view the pattern of distribution of the interstitial fauna was studied with reference to their preferences, if any, to definite grades of the black monazite sands, which are known to have radioactivity. Though the study was conducted during the 3 seasons of the year no data could be collected during monsoon and postmonsoon periods owing to the instability of the beach resulting from heavy erosion. Hence the data available from tests conducted during the premonsoon period alone are presented here.

Sand was collected from the beach, dried and sorted out into different grades, viz. 592-1676, 295-592, 151-295, 104-151 and 75-104 (μ) using sieves. Seven polythene tubes (250 ml; 4 cm diam.) were taken and 5 were filled with the above grades of sand. Of the remaining 2, one was packed with dried but unsorted sand and the other with fresh sand from the beach. All the tubes with both the ends open, were buried horizontally at a depth of about 40 cm from the surface over the mid-tide level on the Neendakara beach, 8 km north of Quilon Town. This is an exposed beach containing fine black monazite sands with some influence of silt.

After 30 days of exposure all tubes were carefully removed. A small portion of the sand from both ends of the tubes was removed to avoid any possible mixing of the sorted sand with the beach sand. Subsamples (20 ml) were then taken and the animals separated from the sand. These were later sorted into groups, identified and numbers counted.

Number of different species of major interstitial groups sorted from each tube is presented in Table 1.

It is evident from the distribution patterns that the tubes filled with graded sand particles were populated by fauna, which are considerably poorer both in number and in species than those found either in the tubes containing ungraded sand or in the fresh beach sand. In general, the total number of animals was reduced in relation to decrease in grain size. Turbellarians and archiannelids favoured sand grains ranging from 151-295μ, while kinorhynchs, polychaetes and copepods preferred grains ranging from 592-1676μ. Cnidarians, nematodes and gastrotrichs exhibited priority for grains ranging from 295-592 μ and tardigrades 104-295 μ. Turbellarians, nematodes, archiannelids and copepods showed a noticeable fall in numbers in grades <151 μ. No animal group was found in the grade 75-104 μ. Polychaetes and kinorhynchs were conspicuous by their absence in grades finer than 151 μ while tardigrades did not occur in grades coarser than 295 μ.

Halammohydra octopodides was obtained only from grades 295-592μ. The abundance of *Acanthomacrostomum spiculiferum* in grade 151-295 μ suggests its preference to this particular range. Of the 5 species of nematodes *Anticoma quadriseta, Thoracostoma amphiodta* and *Enoploides labiatus* chose grains coarser than 592 μ. *Sphaerolaimus campbelli* appeared in greater numbers in the grade 295 -592 μ while *Leptolaimus dorsalis* selected grains ranging from 151-295 μ.

Four species of gastrotrichs, 1 species of kinorhynch and 3 species of archiannelids were studied with regard to their preferences. The incidence of *Pseudostomella roscovita, Tetranchyroderma hystrix, Polygordius madrasensis* and *Polygordius uroviridis* was greater in grades 295-592 μ while *Tetranchyroderma massiliense* and *Cateria styx* preferred grains coarser than 592 μ. *Xenotrichula subterranea* and *Saccocirrus minor* showed a distinct choice for the grade 151-295 μ.

Preponderance of polychaetes and copepods is noticeable in coarse sands (592-1676μ). Both the species of polychaetes preferred grains coarser than 592 μ. With the exception of *Paramesochra wilsoni*, all other species of copepods favoured grains above 592 μ. The only tardigrade, *Stygarctus bradypus* as well as the copepod *Paramesochra wilsoni* showed a priority for grains ranging from 151 to 295 μ.

Boaden[2] has reported that *Protodrilus adhaerens* Jagersten colonised only sand grains with diameter >500 μ while *P. chaetifer* Remane was commonest in sands with particle diameter ranging between 210 and

Table 1—Number of Different Species Colonising the Respective Grades of Sand at Neendakara Beach during Premonsoon Period

Species	Dried sand	592-1676 μ	295-592 μ	151-295 μ	104-151 μ	Fresh beach sand
Cnidaria						
Halammohydra octopodides	2	0	2	0	0	3
Turbellaria						
Acanthomacrostomum spiculiferum	12	3	5	13	4	14
Nematoda						
Anticoma quadriseta	6	6	4	2	0	7
Thoracostoma amphidota	5	7	3	2	0	4
Enoploides labiatus	8	6	5	2	0	7
Sphaerolaimus campbelli	11	8	12	7	1	18
Leptolaimus dorsalis	4	1	2	4	2	5
Gastrotricha						
Pseudostomella roscovita	4	1	4	2	0	5
Tetranchyroderma massiliense	1	3	2	1	0	2
T. hystrix	1	0	2	1	0	2
Xenotrichula subterranea	2	0	1	2	1	3
Kinorhyncha						
Cateria styx	5	6	2	1	0	5
Archiannelida						
Polygordius madrasensis	8	4	6	5	1	7
P. uroviridis	6	2	5	3	0	6
Saccocirrus minor	4	1	2	7	1	3
Polychaeta						
Pisione gopalai	3	3	1	0	0	5
P. complexa	7	8	3	2	0	9
Copepoda						
Arenosetella indica	8	9	5	3	0	10
Ameira trisetosa	4	5	3	2	0	4
Paramesochra wilsoni	6	0	1	6	4	6
Sewellina reductus	5	4	2	2	0	4
Tardigrada						
Stygarctus bradypus	1	0	0	2	1	2

150 μ. The ability to choose a preferred range of sand grains does, however, play some part in limiting species to certain beaches or areas of a beach. *Corophium volutator* Pallas prefers muds with very fine particle size[3] and is found almost exclusively in this habitat. *Cumella vulgaris* Hart is restricted to beaches with particle sizes between 600 and 150 μ as only these particles can be manipulated by its mouth parts[4]. Again Wieser[4] has shown that most interstitial species occur in sands with a mean particle diameter >200 μ. Faure Fremiet[5] has classified ciliates according to their preferred grain size as mesoporal (1.8-0.4 mm grain), microporal (0.4-0.12 mm grain), and euporal independent of grain size. In simple choice experiments between graded sand and ungraded sand, Gray[6] has found that *Protodrilus symbioticus* Giard preferred grain size of between 200 and 300 μ. Jansson[7] has shown that *Marionina subterranea* reacts to different grades of sand by showing preference for grain size between 125 and 500 μm.

From the results discussed it can be concluded that comparatively larger number of animals in coarser sands could be attributed to the increased pore-space available for the interstitial fauna.

Correlation seems to exist between the body size of the interstitial animals and the grain size[2,4,8]. In the present investigation also larger species, viz. *Arenosetella indica, Ameira trisetosa* and *Sewellina reductus, Tetranchyroderma massiliense; Anticoma quadriseta, Thoracostoma amphidota* and *Enoploides labiatus*, the species of polychaetes and the kinorhynch were collected in greater numbers from the coarser grains above 295 μ, while comparatively smaller species such as *Xenotrichula subterranea* and *Paramesochra wilsoni* were obtained in greater numbers from grades ranging from 151 to 295 μ. But the occurrence of certain larger forms such as *Sphaerolaimus campbelli* and *Saccocirrus minor* in greater numbers in grades <592 μ seems to contradict the aforesaid relationship. It is likely that grain size is not the only factor that governs the distribution of organisms on a sandy beach.

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Ecology of *Magelona cincta* Ehlers, 1908 (Polychaeta: Magelonidae) in the Vasishta Godavari Estuary, East Coast of India

D SRINIVASA RAO & D V RAMA SARMA
Department of Zoology, Andhra University, Waltair 530 003

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Quantitative variation of *M. cincta* for 1 yr is presented along with a brief description of the specimen. Its abundance and distribution in relation to the interstitial salinity, substratum composition and organic matter content along the course of the estuary and the slope of the beach are discussed.

Genus *Magelona* Müller, 1858 was first reported by Fauvel[1] off Maldives. The specimen was too young to be identified to the species level and, therefore, identified merely as a juvenile of *Magelona* sp. Damodaran[2] recorded *M. longicornis* off the Kerala coast while Hartman[3] recorded *M. cornuta* in the Indian ocean. Srikrishnadhas and Ramamoorthi[4] working on the ecology of polychaete larvae in the Vellar estuary indicated the presence of *Magelona cincta* at the mouth of the Vellar estuary.

The description of the species given below is based on the specimens collected in December 1976 from the intertidal area of the Vasishta Godavari estuary.

Body up to 15 mm long with a circular reddish band between setigers 5 and 8. Two long palps arise from the anterior end which are papillose distally (Fig. 1a). Prostomium (Fig. 1b) as broad as long, more or less triangular in shape with a pair of muscular strands diverging anteriorly and ending anterolaterally as projections. Proboscis large and unarmed (Fig. 1c).

Body divided into 9 thoracic setigers and posterior abdominal setigers. Thoracic parapodia (Fig. 1d) bear ligulate notopodial postsetal lamellae. Dorsal cirrus absent. Neuropodial lamellae more infrasetal than postsetal. Abdominal parapodia (Fig. 1e) bear subequal tongue shaped postsetal lamellae on both the rami curving towards one another and end pointedly.

Setigers 1 to 9 have simple capillary setae on both the rami (Fig. 1f) while the abdominal setae have many hooks each with 2 teeth side by side above the main fang (Fig. 1g).

Collections were made from 6 permanent stations in the intertidal area of the Vasishta Godavari estuary (lat. 16° 18′ N and long. 81° 42′ E) during December 1976 to January 1978 except in August 1977 when collection was not possible because of high freshwater floods. At each station samples were taken from the 3 tidal levels, viz. mean high water mark (MHWM), mean mid water mark (MMWM) and mean low water mark (MLWM), using a metal frame (20 × 20 × 15 cm).

During the study period temperature varied from 22° to 38°C while the interstitial salinity and dissolved oxygen varied between 0-35‰ and 2.2-6.4 ml/litre respectively. The substratum at sts I and II was dominated by sand fraction while siltyclay fraction increased in the upstream direction. The organic matter content in the sediment varied between 0.73 and 4.25%.

M. cincta was totally absent in the estuary during July-September when the entire estuary remained flooded with freshwater from surface to bottom. It occurred in great abundance during February-June (533/m^2) when the salinity was high. Salinity rose to 24‰ in May even at a distance of 16 km up the estuary. Lowered salinity along with disturbed

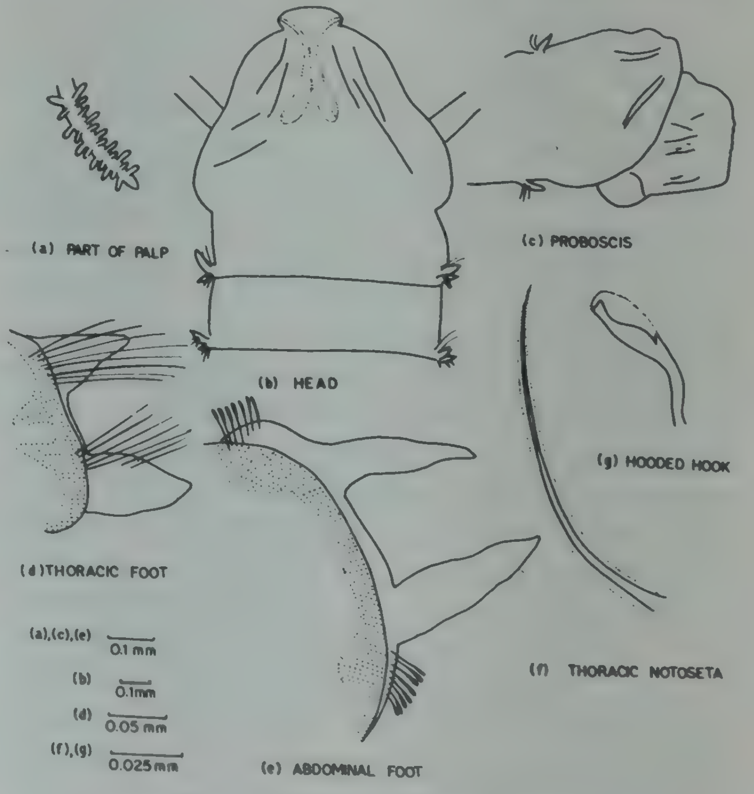

Fig. 1—Various parts of *M. cincta*

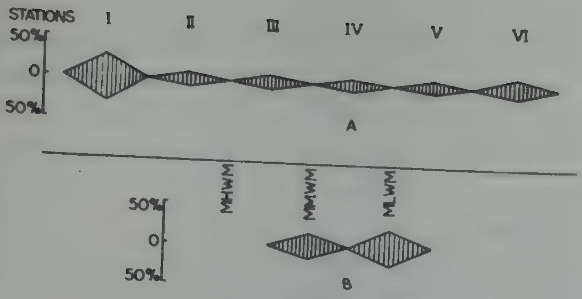

Fig. 2—Relative percentage of appearance of *M. cincta* at each station (A) and tide level (B)

substratum during the annual floods totally wiped out the species from the estuary.

By the end of September when the freshwater floods abate seawater influence extended up the estuary gradually. The salinity gradually rose from 4‰ in October to 18‰ in December. Larvae of *M. cincta* along with many other planktonic larvae obviously enter the estuary from the adjoining neritic waters as they are known to tolerate wide fluctuations in salinity[5]. The lesser competition with the other organisms in the estuary may be the attractive factor for the larvae. Adults started appearing in the estuary from October and the distribution gradually extended higher up the estuary. It reached a maximum density of 533/m^2 in March at st II situated nearly 4.5 km from the confluence. Because of the total disappearance during the low saline period and the recruitment during the recovery season *M. cincta* can be considered as a seasonal migrant following the classification suggested by Panikkar[6].

From the total number of samples taken at each station and tidal level, the relative percentage of appearance of *M. cincta* is calculated (Fig. 2). The polychaete preferred the vicinity of the confluence (st I) where marine conditions dominated during January-June, and more or less showed equal preference to the other stations higher up the estuary. Because of high temperature and prolonged exposure during the low tide the species totally avoids MHWM and mainly confines to MLWM and MMWM where it is constantly bathed by the incoming water.

Relationship between *M. cincta* and the substratum composition shows that it totally avoids sandy substratum and increases its abundance in 50% siltclay substrata (183/m^2). *M. cincta* does not show any relation with organic matter content in the sediment. Perhaps even low concentrations of organic matter may be sufficient for their survival. It looks that salinity is the ecological master factor controlling the quantitative distribution of *M. cincta* in the estuary.

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Chaetognatha from a Sector in the Bay of Bengal

N ANBUSARAVANAN, K KRISHNAMURTHY &
K BALASUBRAHMANYAN
Centre of Advanced Study in Marine Biology
Annamalai University, Parangipettai 608 502

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Species composition and relative abundance of chaetognatha in plankton samples, collected from a sector (17°07′ to 18°20′ N lat. and 84°33′ to 90°06′ E) of the Bay of Bengal, were studied. Out of the 10 species recorded *Sagitta enflata* was dominant. In the gut of most of the specimens, copepods were encountered. Cannibalistic nature of feeding was also evident.

Chaetognaths are usually associated with specific hydrographical environment, thus making themselves as good indicators of water masses, currents, etc[1]. Studies on chaetognaths are necessary as they indicate indirectly the hydrographical conditions in the area, and thus reflect the fertility of the water. Chaetognaths from the Indian Ocean and adjacent waters are reported[2-8]. In the present investigation, an attempt has been made to study species composition and numerical abundance of chaetognaths.

Samples collected from the Bay of Bengal during April 1963 on board *R V Anton Bruun* of the International Indian Ocean Expedition were analysed. The area covered included the stations (sts 55 to 66) extending from 17°07′ to 18°20′N lat. and 84°33′ to 90°06′E long. The samples (12) were collected in a uniform manner with the Indian Ocean standard net[9]. The net was hauled vertically at a winch speed of 1m/sec from a depth of 200m to surface or on the continental shelf from the near bottom to surface.

From each sample, after proper mixing, 20 ml subsample was randomly taken in a counting chamber and the chaetognaths were counted. Numerical values for different species were estimated as number/m^3.

In different stations 2-5 species were recorded. Due to the fairly long period of preservation, important characters used for identification such as number and position of fins, position of gonad, etc. were completely spoiled. It could be the reason for the low incidence of species in the samples. In total, 10 species were encountered while Nair[10] recorded 8-10 species from the same series of stations.

The following species were recorded from different stations (in parenthesis): *Sagitta bedoti* (61, 62, 64, 65), *S. bipunctata* (55, 60, 62 to 64), *S. decipiens* (58, 60), *S. enflata* (55, 56, 60, 61, 66), *S. ferox* (59, 63 *to* 66), *S. hexaptera* (55, 57), *S. neglecta* (56, 57, 61), *S. pacifica* (56, 62, 66), *S. regularis* (57, 58) and *S. robusta* (59, 65).

S. bipunctata, *S. ferox* and *S. enflata* occurred at maximum number of stations (5 out of 12 stations). *S. enflata* showed widespread distribution occurring right from inshore to offshore extremity of stations investigated, closely followed by *S. bipunctata* and *S. ferox* in that order. *S. regularis*, *S. hexaptera* and *S. robusta* showed restricted (occurring at 2 stations only) distribution.

The existence of localised centres of certain species only, found among stations, may be due to their physiology, age, size variations and frequency of brood. The size of chaetognaths showed differences between species.

The maximum chaetognath population was 26,000/m^3 (station 57) and the minimum was 13,000/m^3 (stations 56, 58, 60, 65). However, among species the maximum population density was that of *S. enflata* with 17,000/m^3 followed by *S. hexaptera* with 12,000/m^3. The average population density was around 7,000/m^3.

It is well known that hydrographical parameters alter the abundance of plankton in any region. Based on this, it is possible to draw certain conclusions on the availability of chaetognaths from an area. The surface temperature in the nearshore region ranged from 28.17° to 29.16°C, whereas salinity and dissolved oxygen ranged from 34.18 to 34.95‰ and from 4.61 to 5.25 ml/litre respectively[11]. At the same time the surface temperature in the offshore waters varied from 28.09° to 28.97°C, while the salinity and oxygen values ranged from 34.81 to 34.92‰ and from 4.71 to 4.94 ml/litre respectively[11]. The temperature was relatively low at stations 58 and 60. As reported earlier[7], the presence of cold water would explain the occurrence of *S. decipiens*, a mesopelagic species, at these 2 stations. Rao and Ganapati[12] have reported that *S. enflata* tolerated a salinity range of 17 to 34‰ establishing itself as an euryhaline species.

The maximum length of a specimen was about 35 mm (which belonged to *S. bipunctata*, at station 64). However some shrinkage due to age of preservation is inevitable. The cannibalistic nature of chaetognaths was observed. Most of the specimens were encountered with the copepods in their gut.

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Organic Pollution & *Skeletonema* Blooms in Visakhapatnam Harbour

P N GANAPATI & A V RAMAN
Department of Zoology, Andhra University, Waltair 530 003

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Periodic outbursts of phytoplankton blooms are reported in the Visakhapatnam harbour waters from April to November 1976. These blooms are dominated by a single species of a centric diatom, *Skeletonema costatum*. An attempt has been made to correlate hydrographical and weather parameters with the phytoplanktonic outbursts. It is suggested that the discharge of large scale domestic and industrial effluents and stagnation of the harbour waters owing to inadequate tidal flushing may be contributory factors in the enrichment of nutrients of the harbour waters.

During the study on some aspects of pollution in the Visakhapatnam harbour successive outbursts of the diatom *Skeletonema costatum* in the entrance channel have been observed. In an earlier paper[1] the topography of the harbour and the nature of the domestic and industrial effluents discharged into the harbour waters have been described. Since then an outer harbour has been constructed and this has further retarded the tidal flushing leading to greater stagnation of the harbour waters.

Hydrographical parameters such as dissolved oxygen, nitrite-nitrogen, nitrate-nitrogen, phosphate-phosphorus and salinity in addition to phytoplankton standing crop were measured from April to November 1976 at station II (entrance channel, lat. 17°41′34″ N, long. 83°17′45″ E) in the harbour. The data presented in the paper are based on observations made during low tide on 62 different dates during the study period.

Phytoplankton samples were collected with a tow net (diam. 14 cm; mesh size 70 μm) towed about 0.5 m below the surface and at uniform speed for exactly 1 min, and approximately 300 l of water were filtered. In the laboratory, depending on the concentration of phytoplankton, suitable dilutions were made from which aliquots were drawn for further analysis. Cell counts were made with a Sedgwick-Rafter chamber and expressed as cells per ml. Estimations of dissolved oxygen and nutrients were carried out according to standard methods[2]. Salinity was determined by Knudsen's method. Data on weather conditions (sunshine hours and rainfall) were obtained from the local meteorological observatory.

During the study, several successive outbursts of *S. costatum* were noticed in the Visakhapatnam harbour and their cell numbers on 4 occasions reached bloom proportions (Table 1). The bloom usually lasted for about 12-15 days and the diatom populations reached their peak abundance within about 5-10 days after the onset of the bloom. The maximum bloom intensity occurred during September-October, immediately after a prolonged spell of wet season (16 June-30 August).

The common taxa encountered were *S. costatum*, *Asterionella japonica*, *Chaetoceros armatum* and *Coscinodiscus* sp., of which *S. costatum* was dominant. The densities of this species often exceeded 10,000 cells/ml. On one occasion (14-9-1976) when the phytoplankton density was as high as 604.7×10^2 cells/ml, *S. costatum* alone amounted to 99.6% of the population.

Physico-chemical conditions—Inorganic nitrite content varied from a low value (median 0.04 mg/litre) during 31 October-11 November to a high value (median 0.14 mg/litre) encountered during 26 April-9 May 1976. In general, the values of nitrite-nitrogen remained fairly uniform (Table 1). Inorganic nitrate fluctuated considerably and was undetectable during some bloom periods. Nitrate content was highest (0.29 mg/litre) during the southwest monsoon period (16 June-30 August) when phytoplankton cell count was characteristically at its minimum.

Orthophosphate exhibited even greater concentrations than nitrate and varied in accordance with

Table 1—Variations in Water Quality and Weather Characteristics during Bloom/Normal Periods at Station II (Entrance Channel), Visakhapatnam Harbour

[Data collected during low tide, 1976. Values in Parentheses represent median values]

Bloom/normal period	Date of peak phytoplankton abundance	No. of observations	Dissolved oxygen mg/litre	NO_2-N mg/litre	NO_3-N mg/litre	PO_4-P mg/litre	Cells/ml ($\times 10^2$)	Sea surface temp. °C	Salinity[ʃ] ‰	Sunshine hr	Total rainfall mm
*26 April to 9 May	30 April	6	5.6-6 (6)	0.1-0.24 (0.14)	0.07-0.11 (0.1)	2.4-4.8 (3.54)	8.35-269.8 (88.8)	30.4-32 (31.5)	33.77	7.6-11.4 (10.7)	4.7
11 May to 27 May	—	7	4.6-5.6 (5.2)	0.07-0.17 (0.12)	0.05-0.08 (0.07)	2.6-5.2 (3.18)	5,9-28.5 (22.4)	29-32.2 (30.6)	33.84	5.4-11.7 (9.4)	9.5
*31 May to 14 June	6 June	8	4.2-9.4 (6.2)	0.07-0.14 (0.10)	ND-0.06 (0)	2.24-3.8 (2.98)	13.4-497.4 (96.7)	27.2-30.2 (30.1)	33.84	1.4-11.7 (8.4)	5.6
16 June to 30 Aug.	—	26	4.8-8.2 (6)	0.03-0.55 (0.09)	ND-1.16 (0.29)	2.36-8 (5.22)	0.03-48.9 (3.83)	26.2-30.8 (29.4)	28.68-33.84 (33.49)	0-12.3 (3.9)	245.3
* 4Sept. to 3 Oct.	14 Sept.	7	5.6-13.4 (8.8)	0.06-0.16 (0.07)	ND-0.08 (0)	3.3-6.6 (4.8)	21.4-604.7 (350)	29.8-31 (30.2)	32.16-32.99 (32.45)	0-10.8 (9.5)	53
9 Oct. to 27 Oct.	—	4	6.2-7.8 (6.7)	0.02-0.26 (0.1)	ND-0.06 (0.03)	4.2-4.8 (4.8)	1.22-8.89 (4.63)	29-30.2 (29.6)	28.68-31.83 (30.26)	1.1-11.1 (9.99)	109
*31 Oct. to 11 Nov.	11 Nov.	4	5.4-13 (7.1)	0.02-0.06 (0.04)	ND	0.08-2.36 (2.1)	2.2-124.7 (83.6)	28.4-29.4 (29.2)	14.42-23.21 (21.77)	—	142.2

*Bloom periods

[ʃ] Limited observations

ND = Not detectible

nitrate changes. The highest phosphate value (5.22 mg/litre) was encountered during southwest monsoon months when all the phosphate appeared practically unutilised (Table 1).

Throughout the period of observation except during the southwest monsoon months, the nitrite values were relatively higher than the nitrate values (Table 1). This is clearly anomalous in an environment of oxygen supersaturation. In fact, ammonia content in these waters was also high (NH_3-N, 1.3 mg/litre). High contents of NH_3-N and NO_2-N concomitant with low concentration of NO_3-N and supersaturation of oxygen would appear incompatible. In a polluted marine inlet, Waldichuk[3] encountered a similar situation of higher NO_2-N and/or NH_3-N over NO_3-N under conditions of oxygen supersaturation. This might have been due to rapid utilisation of nitrate by phytoplankton. In the local harbour, nitrification as well as nitrate assimilation by phytoplankton appear to be going on continuously resulting in a situation where the instantaneous concentration of nitrate would appear to be less than that of nitrite. That the nitrate content was higher than the nitrite during a prolonged lag period (Table 1), when assimilation of nitrate was presumably low due to poor stocks of *Skeletonema* further vindicates the argument. However, indepth studies would be necessary to alleviate this anomaly.

In general, the concentrations of nitrogen and phosphorus in the harbour decreased relatively as phytoplankton standing crop increased. The nutrient levels were high when phytoplankton stocks were low (Table 1).

Large amounts of domestic wastes besides the effluents from a nearby fertiliser factory drain into the harbour contributing to the bulk of the nutrient source in the harbour waters. These wastes enter the harbour mainly through 3 channels, viz. the northwest arm, the north arm and the southern lighter channel. Analyses of waters at a station (st. Va, north arm) located upstream, close to the source of discharge of domestic wastes, revealed high concentrations (median of 12 observations) of phosphorus (PO_4-P, 1.6 mg/litre) and nitrogen (NH_3-N, 8.9 mg/litre). High BOD (60 mg/litre) and COD (114 mg/litre) values also characterised these waters, and indicated a high incidence of organic pollution.

Dissolved oxygen concentration was generally high and the median values varied from 5.2 to 8.8 mg/litre, with higher values (median 6-8.8 mg/litre) during the bloom periods over normal periods (median 5.2-6.7 mg/litre). The highest concentration (13.4 mg/litre) was observed during the September bloom. The high dissolved oxygen values were indicative of supersaturation of oxygen at the surface which may be attributed to photosynthesis of *Skeletonema* during blooms.

Sea surface temperature varied from a minimum of 26.2°C during 16 June-30 August to a maximum of 32.2°C during 11-27 May 1976 (Table 1). Surface salinity fluctuated from a minimum of 14.42‰ on 6-11-1976 to a maximum of 33.84‰ encountered during May-June period (Table 1).

Rainfall was maximum during 16 June-30 August. This period was also characterised by low sunshine (3.9 hr; Table 1). During September-November the weather conditions remained comparatively calm.

The investigations have revealed that the harbour waters, polluted with domestic and industrial wastes, are characterised by the preponderance of a specific bloom forming diatom component, *S. costatum*, which periodically burst forth in incredible numbers. Several workers[4-15] noted that enrichment through the addition of nutrients as a result of the discharge of domestic and industrial effluents was a significant factor causing phytoplankton blooms in the sea. The conditions that favoured the local outbreaks of algae were found to be the high input of nutrient into the harbour and its continued accumulation over periods of time, due to inadequate flushing.

Abnormally high concentrations of nutrients indicative of eutrophic conditions in the harbour are attributable to large quantities of discharge of domestic sewage and industrial wastes containing phosphorus and nitrogen. Nutrient enrichment through pollution, of the order of a milligram or more per litre was reported from other enclosed marine areas[3,12,16-18]. Locally, the construction of the outer harbour had affected the tidal flushing, accentuating stagnation and greater building up of nutrient reserves in the harbour. Substantial increase in the nutrient concentration observed during southwest monsoon period may be attributed to poor assimilation of nutrients by phytoplankton owing to decrease in insolation during these months. A dense outburst of phytoplankton followed the periods of such peak nutrient availability in the harbour waters (Table 1).

Hydrographical and climatic conditions also seemed to greatly influence the onset of blooms. Peak phytoplankton crop occurred during periods of calm weather, greater sunshine and reduced fresh water inflow. During June-August, there were no blooms on account of low sunshine (3.9 hr). During the last bloom period (31 October-11 November 1976), the phytoplankton density was very low (220 cells/ml) on days immediately following heavy rainfall (salinity 14.42‰).

Abundance of *S. costatum* has been reported from several other polluted marine areas[9,12,19-24]. *S. costatum* is also well known as an abundant constituent of polluted brackish or marine waters in Europe[25].

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Pollution Status of the Cochin Beach

P S GORE, O RAVEENDRAN & R V UNNITHAN

National Institute of Oceanography, Regional Centre, Cochin 682018

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Indicator bacteria contributing to faecal pollution, and fresh or decaying *Salvinia molesta* debris contributing to biological pollution are identified. Both types of pollution are pronounced during monsoon and postmonsoon months rendering the beach unsuitable for recreational and fishing activities. Premonsoon and late postmonsoon months are almost free of pollution. Qualitative and quantitative population of indicator bacteria and their possible correlation with certain environmental parameters, abundance of fresh or decaying salvinia debris and the overall pollution status of the beach are presented.

Beach as recreational centre is gaining importance. But due to environmental factors like sewage discharge and organic wastes, emanating from human and nonhuman sources, the beaches frequently get polluted and become unsuitable for human activity. Organic wastes such as decaying plant and animal matter, debris, etc. primarily contribute to environmental pollution by increasing the suspended load in water, depleting the oxygen and increasing the hydrogen sulphide and levels of biochemical oxygen demand. One of the most important beach pollutants is faecal contamination of sand and sea water as shown by 'indicator bacteria'. Studies pertaining to faecal pollution of beaches are comparatively few[1-9] and particularly so for Indian coasts[11-13].

Present paper deals with faecal contamination and pollution due to salvinia debris (biological pollution) of Cochin beach.

Study area—Fort Cochin has a plain sandy beach (approx. 1 km long; long. 74°14-15'E, lat. 09°57-58'N) located about 13 km southwest from the town. The 1st transect for sampling is opposite to the tourist resort while the 2nd transect is opposite the cement platform. Fishing operation with castnets, shore nets, and Chinese shrimp nets (dip nets) along the beach is a regular feature.

Average beach expanse (m) at the sampling point was premonsoon, 30-35; postmonsoon, 20-25; and monsoon 5-10. Median diameter (mm) of sand grain at high tide mark was 0.134, mid tide mark 0.153 and low tide mark 0.179. There were no cusps formed and nearshore drift was not significant. Surf zone was shallow and without depressions. There were no rocks infringing into the water and sand dune flora was absent. Upper most part of supra littoral region was guarded with boulders throughout. Wave action was not strong, average wave height during fair season being about $\frac{1}{2}$ m, and about 3 waves/min.

Collections of sand and water samples, processing of samples, transportation, preparation of media and techniques employed in plating, incubation and enumeration of indicator organisms were carried out as reported earlier[13]. Sampling was done fortnightly at about 25 m perpendicular from the coast for 1 yr (November 1976 to October 1977).

Biochemical oxygen demand (BOD_5) was estimated[14]. Hydrogen sulphide (H_2S) was determined using iodometric method. Mohr Khnudsen method was used for salinity measurements. Dissolved oxygen was estimated employing Winkler's method (accuracy ±0.005 ml/litre). Sediment load was estimated by the centrifuge method.

The bacterial counts, given in Table 1, are the average of pooled duplicate samples from transects 1 and 2 of both the fortnights in the month. In all a total of 288 samples of sand and 96 samples of surf beaten sea water were examined.

Faecal contamination—Indicator bacteria occurred in most of the months in sea water and in beach sand in both the transects (Table 1). No appreciable fortnightly variations of counts were recorded for beach sand and sea water. In general, higher counts were recorded in sand than in sea water, as reported for Cherai beach[13]. Monsoon months (June and July) registered higher population counts than other months. The highest incidence recorded in July 1977 was due to lowering of salinity with the monsoonal flow which provided suitable concentration for the survival of indicator organisms. This was in agreement with the trend of bacterial population in the closeby Cherai beach[13] also. However, the maximum counts observed in Fort Cochin beach (134 coliforms, 33 *E. coli* and 35 *S. faecalis*/g sand) were far above the counts encountered in Cherai beach[13] or from Colva beach, Goa[11], while it was comparable to Siridaon beach, Goa[12]. Thus Siridaon beach and the beach under study, presented similar bacteriological status. Macrofaeces were not recorded throughout the course of investigation in sea water while they were often present in beach sand in certain months.

FC/FS ratio was worked out as suggested by Finstein[15] and is presented in Table 1. Nonhuman type (NH) occurred throughout the investigation except in January, March and July 1977 when it was human type (H type). The nonhuman type was contributed principally by dead animals washed ashore during that period.

Table 1—Bacterial Counts at Cochin Beach during Different Months of Study

[Values are expressed in number/g sand or/ml water]

Month	Coliform	*E. coli*	*S. faecalis*	FC/FS ratio
		1976		
Nov.				
S	17	10	13	1 NH
W	7	3	7	0.4 NH
Dec.				
S	8	2	6	0.3 NH
W	Nil	Nil	1	—
		1977		
Jan.				
S	22	6	2	3 H
W	20	3	4	1 NH
Feb.				
S	27	5	5	1 NH
W	1	Nil	1	— NH
March				
S	20	7	10	1 NH
W	33	4	2	2 H
April				
S	14	4	5	1 NH
W	16	2	5	0.4 NH
May				
S	12	5	5	1 NH
W	14	1	7	0.1 NH
June				
S	38	11	9	1.2 NH
W	31	8	6	1.3 NH
July				
S	89	18	10	2 H
W	72	21	5	4 H
Aug.				
S	16	3	3	1 NH
W	5	Nil	2	— NH
Sept.				
S	21	3	5	1 NH
W	20	1	5	0.2 NH
Oct.				
S	22	5	4	1.2 NH
W	22	2	3	1 NH

S = sand; W = water; NH = nonhuman; H = human

Bacterial counts > 100,000 colonies/g sand suggested a health hazard similarly 300 colonies of fungi in sand indicated risk of fungal infection. In a survey[9] of 40 bathing beaches around the English coast, known to be contaminated with sewage, only 4 cases of paratyphoid fever probably due to bathing were recorded. Greenburg[16] pointed out that enteric organisms can create health hazard. Berger *et al.*[4] in their review on coliform standard for recreational waters cited a number of cases where bathing in sewage polluted water caused suspected fever in Perth. Stevenson[8] showed when maximum permissible number (MPN) was 2,400 coliforms/100 ml there was no significant increase in the incidence of illness in swimmers. Maximum acceptable count in different countries for coliforms was 10,000/litre of water and the same for *S. faecalis* was 200/litre[7]. Stevenson[8], reported that MPN > 2,400/100 ml of coliforms is often recommended as MPN for bathing beaches. In the present beach, maximum count registered was 45/ml in July (monsoon period) while during fair season (September to April) the average count ranged from 10-15/ml, which was much lower than the permissible limits. Therefore, based on the faecal coliform counts, it may be observed that the beach is not 'objectionable' for bathing or for other recreational activities during fair season. Even the *S. faecalis* counts were below the 'objectionable' level during fair season.

Environmental parameters—Dissolved oxygen, salinity, biochemical oxygen demand (BOD_5), sediment load and hydrogen sulphide exhibited marked correlation with the bacterial population counts, while atmospheric temperature, water and sand temperature and *p*H did not affect the population since their variation was not significant (Table 2).

Salinity: During premonsoon and postmonsoon months, when the salinity values were higher, the counts of bacteria showed a declining trend. Higher counts were recorded in monsoon months (June and July) as dilution of sea water offers better survival chances for the microorganisms.

Biochemical oxygen demand: Indicator bacterial population and BOD_5 values showed a marked correlation. Months of high BOD_5 values registered high bacterial population while the inverse was true in months with low BOD values (Table 2). Excessive aggregation of decayed salvinia debris may principally be responsible for high BOD_5 values in the environment.

Sediment load: A well defined correlation existed between counts of bacteria and sediment load values. Monsoon months were characterised by high sediment load values and correspondingly high population of indicator organisms. Monsoon currents bring up the mud from the substratum which contributes to the sediment load. Bacteria may find suitable conditions for adhering on mud particle which offers better survival. However, inverse relationship was noticed during the premonsoon months.

Hydrogen sulphide: Direct correlation was noticed between bacterial population and H_2S values. Low H_2S values were followed by low bacterial counts particularly in premonsoon months while it was reverse in monsoon months.

Biological pollution—Large quantities of African weed *Salvinia molesta* gets washed ashore during monsoon months. Quantitative abundance of the weed in the surf zone is so much that it practically cloggs the entire area. The beach is virtually covered with the weed in various stages of decay during monsoon and postmonsoon months. During the late postmonsoon months due to wave action the weed gets covered with sand and embedded ($>\frac{1}{2}$ m) in the vertical axis. The hazardous effects of the weed may be summarised as follows:

(1) Quantitative abundance of the weed in varying stages of decay caused considerable damage to shore fishing operations (dip nets and cast nets) by clogging the nets.

(2) The weed interfered with swimming even during the postmonsoon months, since it harboured large numbers of fungi and bacteria causing considerable dermal irritation to swimmers[17].

(3) Decayed debris of the weed caused depletion of oxygen enhancing the BOD_5 and H_2S levels, thereby creating conditions not suitable for inshore fishes. This affected the shore seine fishery operations considerably.

(4) Large quantities of the weed in varying stages of decay contributed to the organic matter, discoloured the beach sand and presented an 'unhealthy' picture of the beach.

The weed completely disappeared by November/December and the beach was devoid of

Table 2—Environmental Parameters at Cochin Beach during the Study Period

[Diss. Oxygen, sed. load, BOD and H_2S are expressed in mg/litre]

	Temperature °C			Diss. oxygen	Salinity	*p*H	Sed. load	BOD	H_2S
	Atmos.	Sand	Water						
				1976					
Nov.	32.75	31.6	30.25	4.42	19.05	6.8	0.17	10.15	1.77
Dec.	32	32.5	30.5	3.43	20.36	7.3	0.12	9.93	1.3
				1977					
Jan.	31	31	29.5	6.33	27.35	7.2	0.001	8.7	0.85
Feb.	31.9	30.25	29.75	5.74	30.35	7.35	0.001	5.44	0.01
March	34.5	33.9	33.62	5.64	30.93	7.37	T	2.2	T
April	32.5	32.87	32.1	5.74	31.55	7.65	0.007	T	0.2
May	29.25	30.25	29.87	5.54	26.21	7.4	0.12	9.84	0.72
June	25.27	26.9	25.2	3.62	18.56	7.1	0.2	10.94	1.23
July	28.62	27.75	26	3.57	17.78	7	1.29	11.58	1.46
Aug.	31.7	31.55	30.85	3.5	20.44	7.2	0.66	9.52	1.1
Sept.	32.26	31.02	29.5	5.14	23.5	7.36	0.5	3.01	0.78
Oct.	29	31.75	27.75	3.3	23.11	7.6	0.17	7.55	1.76

T = traces

weed pollution during late postmonsoon and premonsoon months. It may be noted that the environment is free of biological pollutant during late postmonsoon and premonsoon months which coincided with 'unobjectionable' months referred for faecal contamination. Total absence of macrofaeces, disappearance of salvinia and improvement in the physico-chemical conditions of the environment during the late postmonsoon and premonsoon months offered a presentable status to this beach above the 'objectionable levels' of pollution.

The authors are grateful to Dr S.Z. Qasim, Director, for his interest and encouragement in the investigation.

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Trace Metals in Zooplankton from the Bay of Bengal

M D GEORGE & TARIQ W KUREISHY
National Institute of Oceanography
Dona Paula, Goa 403 004

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Zooplankton samples, collected during the 20th and 21st cruises of *RV Gaveshani* in the Bay of Bengal, were analysed for their trace element concentrations. The concentrations were comparable to the values obtained by other workers in different areas.

Determination of heavy metals in biological material of the sea has attained practical importance with the increased awareness of the dangers of marine pollution. So far little work[1-6] has been done on the multi-element determination in bulk collections of zooplankton.

Zooplankton are of much importance in the cycling process of elements in the oceans. Though the concentrations of metals in zooplankton vary because of many reasons, they do indicate possible environmental characteristics of a particular region. Moreover, being a major source of food for larger animals, their role in the transfer of metals to higher trophic levels is of much importance. The present study deals with the determination of Cu, Fe, Co, Ni, Pb, Mn and Zn in zooplankton from the Bay of Bengal. This work forms a part of the programme on monitoring different pollutants in the biological material from the Indian waters.

All collections were made during the 20th and 21st cruises of *RV Gaveshani*. Zooplankton samples were collected using an HT Net (mesh size 0.2 mm) from the stations shown in Fig. 1. The net was towed for 15 min while the ship was moving dead slow. The metal frame of the net was covered by a canvass sheet and a PVC bucket was used. On completion of the tow, the net was not washed with the ship's sea water supply[7]. The plankton cake was transferred to polythene bags directly from the bucket, with the help of a precleaned glass rod, after draining the water out. All samples were frozen at −5° to −10°C on board.

On reaching the shore laboratory, the samples were thawed and dried at 60°C in petri dishes. Dried material (1-2 g) was weighed accurately and then transferred to a 100 ml conical flask. The material was digested in conc. HNO_3 (15-25 ml) followed by concentrated perchloric acid until a clean solution was obtained. Blanks were run along with the samples. The acid volume, reduced to 1-2 ml, was transferred to a 10 ml flask and made up to the mark with glass distilled water. The solutions were examined for trace metals

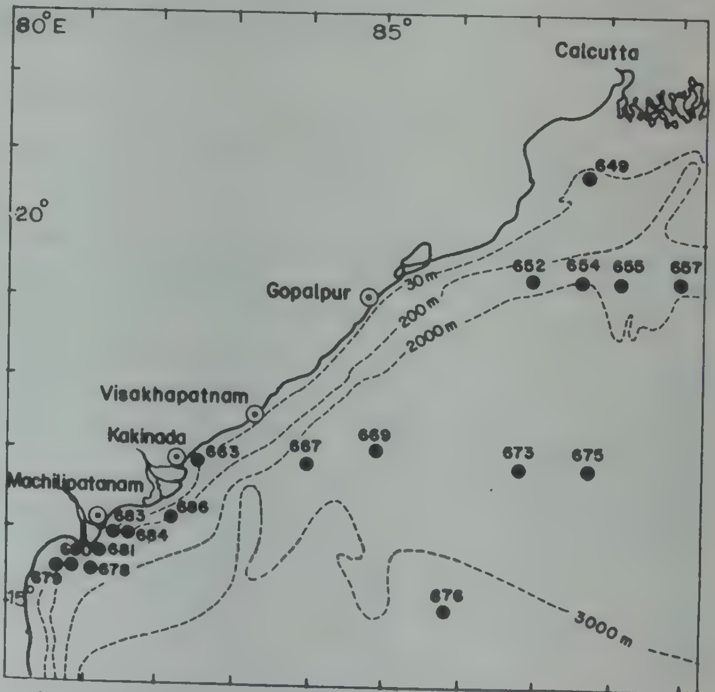

Fig. 1—Location of stations (Numbers refer to oceanographic station starting with cruise 1 of *RV Gaveshani)*

using standard atomic absorption techniques[5]. Calibration curves were prepared for each metal using the standards.

The accuracy of the method used was checked by analysing the reference sample of the fish flour used in the 1975 ICES trace metal intercalibration exercise. The results (Table 1) are in agreement with those of other laboratories[8]. Coefficient of variation, except for Pb, was between 5 and 10% (Table 1).

Table 2 gives the results of the analysis. Average concentrations were computed for all the samples analysed and the values compared with those obtained by other workers.

A preliminary analysis on species composition of zooplankton samples, based on the other sub-samples revealed that copepods were most dominant in all the samples. Chaetognaths were next in abundance followed by euphausids[9]. It is felt that the small change in the composition may not contribute significantly to the wide variation of values as observed here.

Table 1—Result of Standard ICES Fish Flour Analysis (ppm)

	Cu	Co	Ni	Pb	Fe	Mn	Zn
Mean value	4.92	1.82	0.256	2.41	745.73	15.85	46.54
SD	0.4	0.18	0.24	0.51	47.56	0.79	2.7
Coefft. of variation	8.13	9.89	9.38	21.16	6.38	4.98	5.8

The most interesting observation is that the zooplankton from the offshore areas showed high values as compared to zooplankton from the coastal stations. St 649 off Hooghly estuary shows low values as compared to st 652 and 654 far off the Hooghly estuary for most of the metals. This is not as significant as the difference in between the other coastal and offshore stations (Table 2). On a comparative basis all the coastal stations, barring st 663 which is at the mouth of a tributary of river Godavari, show lower values for all the metals than the offshore stations. Since there are no data on the concentrations of trace metals in sea water and particulate matter from the Bay of Bengal, at each of these stations, it is rather difficult to assign any reason for the occurrence of high values in offshore samples. The peculiar gyral circulation pattern in the Bay of Bengal may be an important factor for the high concentration in the offshore samples. Since the coastal areas have a large amount of solid particles, the metals are adsorbed on these particles and are probably removed more quickly by sinking to the bottom than in the open ocean which has very little particulate matter. This has been shown to be true in the case of chlorinated hydrocarbons[10]. However, more information is needed to support the above assumption. Significantly high concentrations of Pb are found in the offshore samples. High concentration of Pb has been reported from different

Table 2—Trace Metal Concentration in Zooplankton (ppm dry weight)

St No.	Cu	Co	Ni	Pb	Fe	Mn	Zn
649	25	5	61	173*	2803	143	1378*
652[a]	153	16	17	—	4873	110	1700*
654[a]	12	8	14	208*	3161	172	938
655[a]	10	2	1	11	127	7	109
657[a]	31	8	10	5	1255	62	680
663	—	26	26	—	4121	249	1390*
667[a]	24	11	21	119	961	27	490
669[a]	97	31	6	63	684	17	592
673[a]	228	32	81	—	2443	66	1530*
675[a]	—	17	50	—	6930	133	—
676[a]	81	5	11	54	2424	45	1237*
678	—	ND	29	58	1363	19	—
679	52	16	17	170*	1411	37	816
680	4	6	5	8	134	7	105
681	3	2	2	7	145	6	46
683	20	3	2	5	82	5	107
684	—	9	12	—	1162	34	514
686	—	ND	30	185*	4011	95	1701*
Mean(18)[f]	33	11	21	37	1139	31	440
Martin[3] (22)	41	13.33	42	49	1200	28	428
Szabo[2] (5)	30	1	19	—	1133.3	11.3	266.6

*Not included for calculating the average

[f] Values in parentheses indicate number of samples analysed

ND = Not detectable

[a] Offshore stations and the rest coastal

areas[1-3]. However, present results suggest a possible build-up of this 'non-essential' element in the biota of Bay of Bengal, for reasons still unknown.

The concentration factor for each metal, except Pb, was calculated. The concentration factor was highest for Fe (15638) followed by Co (1955), Zn (1042), Ni (442), Mn (358) and Cu (228). According to Bowen[11], among cations, the affinity for living matter is in the order tetravalent and trivalent elements > divalent transition metals > divalent group II A metals > univalent group I metals. When the concentration factor was arranged in the decreasing order, the above statement was found to hold good for all elements except Zn.

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Energy Value of Suspended Detritus from Some Stations along the West Coast of India

SUMITRA-VIJAYARAGHAVAN, M V M WAFAR & L KRISHNA KUMARI
National Institute of Oceanography, Dona Paula, Goa 403 004

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Energy content of suspended detritus was determined from the coastal waters of the west coast of India during the 31st cruise (March-April 1978) of *RV Gaveshani*. Percentage contribution of energy by phytoplankton, zooplankton and detritus in total suspended matter amounted to 5.05, 13.8 and 81 respectively. The caloric value of the detritus ranged from 490 to 5094 cal/g dry weight. The results indicated the predominance of detritus over living matter.

Detrital particles generally form the major component of suspended matter in the sea and play an important role in physical, chemical and biological processes[1]. The importance of detritus in the food web has been indicated[2-6]. However, information on nutritive value of detritus during its formation in the tropical waters is very limited[7,8]. The present communication deals with some aspects of the caloric content of suspended detritus.

Water samples were collected from different depths using van Dorn sampler from 7 stations (lat 13° 30′ N to lat 10° N) during the 31st cruise of *RV Gaveshani* (March-April 1978) in the Arabian Sea. To quantify the amount of total suspended matter, 4 to 9 l of water sample was filtered through GF/C Whatman filter paper and dried in an oven at 70°C. Chlorophyll *a* was estimated fluorometrically and converted to phytoplankton carbon using the conversion factor given by Tranter[9]. Zooplankton biomass data available as displacement volume/m^2, collected during the 17th cruise of *RV Gaveshani* (March 1977) from the same area, were used for computing zooplankton carbon values following the conversion factor of Tranter[9].

Phytoplankton calories were derived from the carbon values using the conversion factor given by Platt and Irwin[10]. Zooplankton carbon was converted to caloric value using the conversion factor 1 mg C = 10 calories[11]. Energy content of total suspended matter was determined by combustion of the dried material in a Parr adiabatic microbomb calorimeter. Detrital calories were obtained by the difference between the total suspended matter calories and phyto- and zooplankton calories. The results given here represent the integrated column production values.

Integrated values of phytoplankton, zooplankton and detrital calories are given in Table 1. On an unit weight basis, the calorific value ranged from 490 to 5094 cal/g dry weight (av. 1601 cal/g dry weight). The mean detrital caloric value recorded in the present study appears to be lower than that reported for Red Sea, Gulf of Aden, Equatorial Atlantic, Gulf of Mexico[12], Menai Straits[13] and the Laccadive Sea[8] but higher than that reported for Cochin backwaters[6] and Zuari estuary[7].

Table 1—Integrated Energy Values of Phytoplankton, Zooplankton and Suspended Detritus at Different Stations in the West Coast of India

Station No.	Depth range (m)	Energy kcal/m^2		
		Phytoplankton	Zooplankton	Detrital
875	0-50	0.654	2.4	78.646
877	0-50	0.599	1.8	71.851
878	0-50	1.642	9.6	5.858
879	0-45	3.061	1.8	79.188
880	0-45	1.271	1.8	27.383
881	0-37	1.602	2.4	6.765
882	0-30	0.358	1.2	23.75

Percentage contribution of energy by phytoplankton, zooplankton and detritus in the total suspended matter was 5.05, 13.8 and 81.16 respectively. Thus, the major part of the available energy appears to be contributed by the detrital fraction as observed earlier[7,8]. Saunders[14] also pointed out that in coastal regions, approximately 90% of the particulate matter is detritus.

When the total investigated area (15.7×10^3 km^2) of the west coast is considered, the distribution of energy would be 20.598×10^9 kcal by phytoplankton, 47.1×10^9 kcal by zooplankton and 658.144×10^9 kcal by suspended detritus.

Chemical analyses indicate that the detritus in the sea is composed of 30% carbohydrate, 70% fibrous material and >1% lipid[15]. Then, in the present study, of the total detrital energy available (658.144×10^9 kcal), 197.443×10^9 kcal is probably contributed by carbohydrates and 460.701×10^9 kcal by fibrous material.

Detrital matter generally includes plant detritus, animal detritus, faeces of heterotrophs and moulted exoskeleton of crustacea. According to Petipa *et al.*[16] in the upper layers of the sea, plant detritus usually is about 8%, animal detritus 10%, faeces 1.2% and exoskeleton 0.03% of the standing stock. If that is applied here, the contribution by the dead plant cells would amount to 1.648×10^9 kcal, zooplankton detritus 4.71×10^9 kcal, faeces about 0.565×10^9 kcal and exoskeleton 0.014×10^9 kcal. From the above it is evident that the major source of detritus in the west coast is not autochthonous but the area being coastal region, it might have originated from terrigenous sources (allochthonous).

Saunders[14] pointed out that in the upper few hundred meters of the oceans, predominance of detritus is a common phenomenon. He attributed it to the fact that freshly formed detritus is not easily assimilated by animals as it is by microorganisms and well formed or decomposed detrital aggregates are less susceptible to bacterial attack. This may be probably the reason for the dominance of detritus over the living biomass observed in the present study as well as in the Laccadive Sea[8].

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Energy Content of the Wedge Clam, *Donax incarnatus* Gmelin

T BALASUBRAMANIAN, SUMITRA-VIJAYARAGHAVAN & L KRISHNA KUMARI

National Institute of Oceanography, Dona Paula, Goa 403 004

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Seasonal variations in energy, organic carbon and lipid contents in *D. incarnatus* were studied for 1 yr. Caloric content varied from 2.74 to 5.35 kcal/g dry weight in males; the range of variations in females and indeterminate forms was 3.59 to 5.3 and 3.19 to 5.59 kcal/g dry weight respectively. Variation in the energy content in females was closely associated with the spawning cycle and lipid content.

Clams are found in abundance in the estuaries, backwaters and bays of both east and west coasts of India. Exploited resources of clams from natural populations are >5000 tonnes, although their potential is very high[1]. Earlier studies on the wedge clam *Donax incarnatus* of west coast of India are either restricted to its biology[2,3] or to oxygen consumption and feeding experiments[4]. McLusky *et al.*[3] have reported that the sandy beaches of Goa (Calangute and Colva) are dominated by the *Donax* spp. In this communication seasonal variations in energy content, organic carbon and lipid of *D. incarnatus* are presented.

D. incarnatus was obtained regularly at fortnightly intervals from Colva Beach for 1 yr (November 1974 to October 1975). The animals were collected using a sieve (0.5 mm mesh) from those levels of beach where *Donax* was abundant and the length of each animal measured. In total, 1666 animals were analysed for this study, covering a range of 6 to 24 mm in length. Based on the gonadial condition, the animals were sorted into males, females and indeterminate forms, and soft tissue was separated from the shell and dried in an oven at 70°C. The dried material was homogenised and estimations of caloric content[5], organic carbon[6] and lipid[7] were made. The calorific values were later corrected by Bomb calorimetry.

Seasonal variations in the caloric content in all the 3 categories of *D. incarnatus* are shown in Fig. 1. Males were absent during June. In males, from November to February there was a declining trend in caloric value touching the lowest in February, followed by the highest value in March and then slowly registering a decline. Between July and September, the caloric value was around 3.35 kcal/g dry weight, followed by a rise in October. In females, except for a decline in February and June the caloric content remained around 4.4 kcal/g dry weight between November and May. The peak value occurred in August. In indeterminate forms, the peak values occurred during December, March and June and the minimum value in July. Rest of the months the values were around 4.02 kcal/g dry weight.

Comparative caloric values and lipid values of *D. incarnatus* and of other species of *Donax* recorded from India and elsewhere are given in Table 1. The caloric value recorded for *D. incarnatus* in this study is comparable with the values given for other species. Caloric content in the females dropped sharply during February and June (Fig. 1). While examining the gonads, it was found that although adult recurring forms were present throughout the year, their maximum abundance was during May to August (39, 54, 51 and 45 % respectively). Since the recurring forms are indicative of spent condition, it is possible that spawning might have taken place just before these

Table 1—Comparison of Caloric Values and Lipid Values of Different Species of *Donax*

Species	kcal/g dry wt[ʃ]	Lipid (%)	Region
Donax cuneatus[8]	3.78	8.49	Tondi-India
D. incarnatus[9]	4.65	9.23	Shertallai-India
D. incarnatus[9]	4.46	4.53	Cochin-India
D. spiculum[9]	4.7	5.14	Cochin-India
D. vittatus[10]	4.85	8.04	Millport
D. vittatus[10]	4.93	10.81	Scotland
*D. incarnatus**	4.17 (♂)	11.62	Goa-India
	4.36 (♀)	13.35	
	4.24 (Ind)	11.41	

*Present Study

[ʃ] Values computed from biochemical composition except in present study

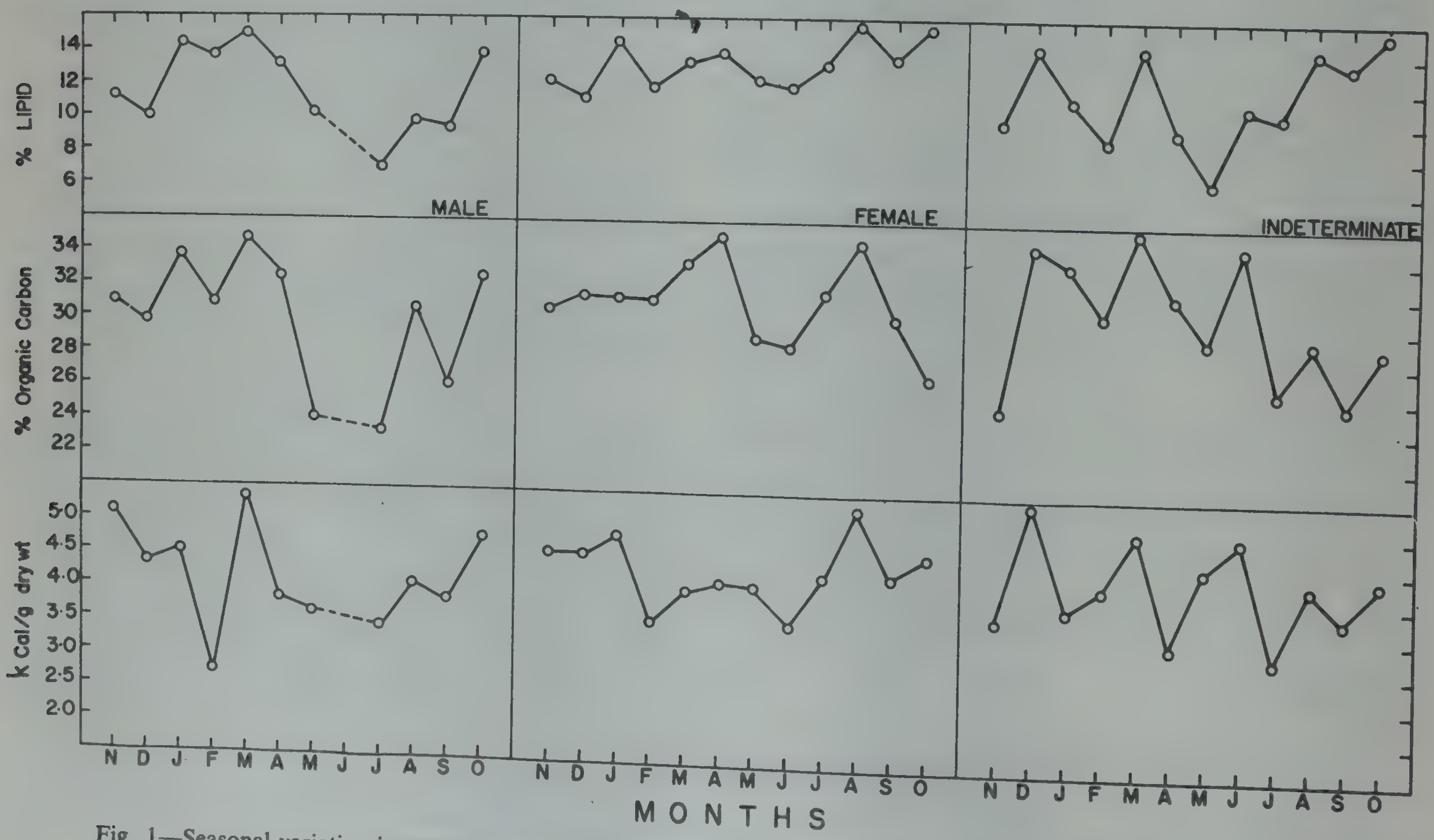

Fig. 1—Seasonal variation in energy content of *D. incarnatus* [Results average of fortnightly values for each month]

months, hence, indirectly the decline in caloric value in females could be associated with spawning condition. Ansell *et al.*[2] reported that caloric content of *D. vittatus* showed peak value during pre-spawning and decline on spawning.

The general trend in organic carbon content (Fig. 1) followed that of caloric values in males, with a few exceptions. The maximum value in March coincided with the maximum caloric value but the minimum value of organic carbon was recorded in July. In case of females, carbon values revealed a steady increase from November to April, reaching a maximum value of 35.27% in April. This was followed by a decline until June, thereafter rose again up to August and declined in October (26.14%). The trend in organic carbon values in indeterminate forms followed that of calories. High values in December, March and June coincided with those of high caloric values recorded during the same months. Minimum caloric value was observed in July while that of organic carbon was recorded in September.

Lipid content in case of the males, registered fairly high values between November and May followed by a decline in July and slowly rose till October. Peak value was recorded during March. The trend in females followed generally that of caloric values except during December, in that the peak values were obtained during January and August. In case of indeterminate forms, high values of lipid recorded during December (14.28%), March (14.06%), August (14.13%) and October (15.21%) coincided with the high caloric and carbon values during the same months. However, the lowest value obtained in March did not correspond with the low carbon and caloric values. Significant correlation ($r = 0.6071$) was obtained between caloric and lipid contents in females, while it was not significant in males and indeterminate forms. Thus, in case of females, seasonal changes in lipid content follow changes in caloric values and appear to be correlated with reproductive cycle.

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Amylase Activity of the Digestive System in Marine Penaeid Prawns, *Parapenaeopsis hardwickii & P. stylifera**

G K KULKARNI, R NAGABHUSHANAM & P K JOSHI

Department of Zoology, Marathwada University, Aurangabad 431 004

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Maximum amylase activity was found in the midgut gland whereas it decreased in the foregut and hindgut parts. In both the species the optimum *p*H for enzyme activity was little less than 7 while optimum temperature was between 32°C and 38°C. Maximum activity of this enzyme was found when the substrate concentration was between 3 and 3.5% in *P. hardwickii* and 2.5 and 3% in *P. stylifera*.

Presence of different digestive enzymes like proteolytic, amylolytic and lipolytic enzymes, in the midgut gland or in different parts of the alimentary canal of various crustaceans has been reported[1-5]. Digestive enzymes have been studied extensively in decapods and particularly the amylase activity[6-9]. However, no information is available on the distribution and functional characteristics of amylase in the food canal and digestive system of the 2 commercially important prawns, *Parapenaeopsis hardwickii* and *P. stylifera*.

Parapenaeopsis hardwickii and *P. stylifera* (Crustacea, Decapoda, Penaeidae), in intermoult stage, were collected from the coastal water of Versova, Bombay, brought to the laboratory, and held in glass aquaria containing constantly aerated sea water (sal. 32-33‰; temp. 23-25°C). They were starved and acclimatized to the laboratory conditions for 48 hr. They were then sacrificed, midgut gland, foregut and hindgut were dissected out and stored at 0°C separately. These parts were washed with distilled water, homogenized and centrifuged at 0°C. Aqueous extract (1%) was prepared from suparnatants and used as the source of enzyme. Few drops of toluene were added to prevent fungal or bacterial contamination and the extracts used immediately.

Amylase activity was determined by Oser's method[10] using dinitro-salicylate reagent (DNSA).

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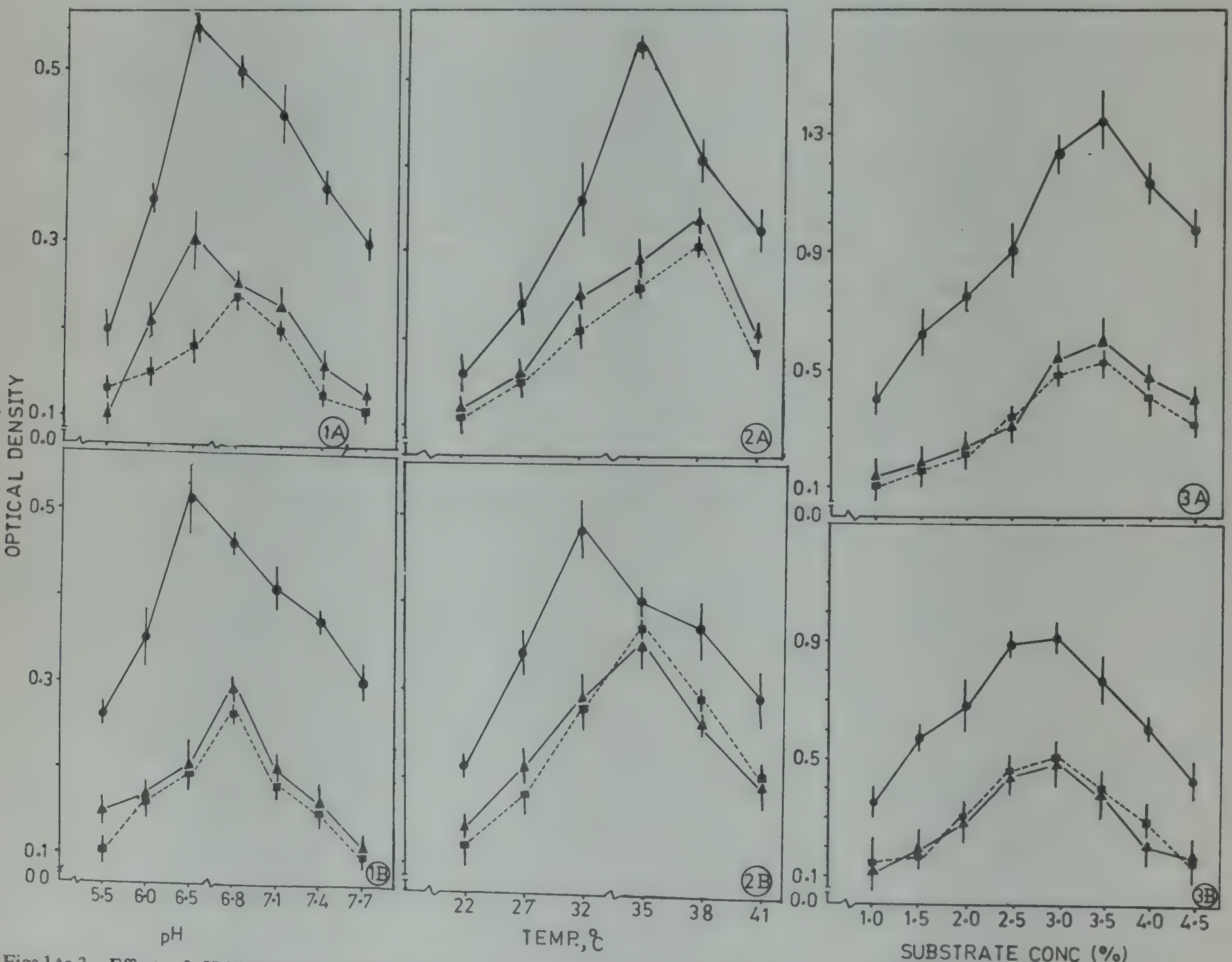
The reaction mixture contained (ml) 1% starch solution as substrate, 1; 0.5% NaCl as enzyme activator, 1; Sorensen's phosphate buffer, 2; and enzyme extract, 1. Effect of *p*H on the amylase activity was determined using different buffers (*p*H 5.5 to 7.7). To study the effect of temperature, the reaction mixture at optimum *p*H was incubated at different temperatures for 30 min. The influence of substrate concentration on the amylase activity was ascertained using different concentrations of starch solution (1% to 4.5%) at optimum *p*H. The reaction mixtures were incubated for 30 min at 37°C and the optical density measured at 530 nm using specol. In all experiments boiled extract was used as control. Experiments were repeated thrice under each category and results averaged.

*p*H optimum for amylase activity was 6.5 for midgut gland and 6.8 for hindgut in *P. hardwickii* (Fig. 1A). In *P. stylifera* the midgut gland showed maximum enzyme activity at *p*H 6.5 while foregut and hindgut showed optimum activity at *p*H 6.8 (Fig. 1B). The optimum *p*H for amylase activity in midgut gland was reported to be 7 and 7.2 in *Penaeus indicus*[1] while in *Caridina weberi*, it was 6.8 (ref. 5). In *Homarus americanus*[8] optimum *p*H for amylase activity of stomach juice was 5.5. Present results agree well with those reported for *P. indicus*[9] and *Metapenaeus monoceros*[9].

In *P. hardwickii* the optimum temperature required for the maximum amylase activity of midgut gland was 35°C whereas for foregut and hindgut, it was 38°C (Fig. 2A). In *P. stylifera*, for the midgut gland 32°C was the optimum activity temperature while for foregut and hindgut it was 35°C (Fig. 2B). Present results are well supported by the observations of Karunakaran and Dhage[9] in *P. indicus* and *M. monoceros*.

Not much information is available regarding the effect of substrate concentration on the amylase activity in the marine prawns[9]. In the present study, the optimum substrate concentration required for maximum amylase activity in midgut gland, foregut



Figs 1 to 3—Effects of *p*H (1), temperature (2) and substrate concentration (3) on the amylase activity in *P. hardwickii* (A) and *P. stylifera* (B) [Vertical lines indicate the range of variability from mean. ●, Midgut gland; ▲, foregut; and ■, hindgut] and hindgut of *P. hardwickii* was between 3 and 3.5% (Fig. 3A) whereas in *P. stylifera* it was between 2.5 and 3% of substrate (Fig. 3B). The present results suggest that the nature and activity of the enzyme (amylase) depends on the feeding habits of *P. hardwickii* and *P. stylifera*.

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Feeding Behaviour & Preying Efficiency of *Metapenaeus dobsoni*

T BALASUBRAMANIAN, C B LALITHAMBIKA DEVI & M KRISHNANKUTTY

National Institute of Oceanography, Regional Centre, Cochin 682018

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Experiments on feeding behaviour and food preference using selected prey species indicate that *M. dobsoni* is a voracious feeder. Two day starved active prawns feed continuously with only short breaks. Ingestion and digestion rates seem to be nearly equal in actively feeding prawns. Prawns browse actively over the substratum using the chelate legs to identify and capture food organisms. *Apseudes chilkensis* (Tanaidaceae) a semi-sessile form occurring abundantly in the study area is highly preferred, while a related species *A. gymnophobia* is avoided. Live and freshly killed organisms are much preferred to dead and decaying animals. Preying efficiency of prawn decreases with increasing quantities of mud in the substratum. Depth of water exerts no influence on the preying efficiency.

In certain regions of Cochin backwaters which form the main nursery ground for commercially important penaeid prawns, bottom organisms like amphipods, tanaidaceans and polychaetes occur in great abundance. Most of them are highly preferred as food, amphipods and tanaidaceans often forming >40% of the crustacean remains in their gut[1]. This paper presents feeding behaviour and preying efficiency of *Metapenaeus dobsoni* under controlled laboratory conditions.

Juveniles of *M. dobsoni* were collected during November 1976 to May 1977 and May 1978 from natural tidal ponds located in the southern end of Ramanthuruth island (lat. 9°58′50″N, long. 76°15′40″E) near the harbour entrance. During each sampling adequate quantities of the substratum (muddy sand), water and prey animals consisting of 2 species of amphipods and 1 tanaidacean were collected. Prawns were collected using small ring net. The prey species were separated from the mud using a sieve (500 μm) and sorted from the decaying organic matter. The mud was sieved using Endecott Sieve No. 35 (mesh size 500 μm) to remove macrobenthos.

Experiments were carried out on 2 day starved prawns of nearly same weight range. Most of the experiments lasted for about 1 hr except the 2 on satiation limit which lasted 4 and 5 hr respectively. Experiments were conducted on individual prawns kept in 500 ml beakers except the one on the effect of the depth of water on preying efficiency which was carried out in 4.25 l rectangular troughs. The experiments were conducted in replicates.

Food preference, satiation limit, effect of mud and depth of water on the preying efficiency and mode of feeding were examined.

Food preference—In the sampling locality the tanaidacean *Apseudes chilkensis* was most dominant while the amphipods *Eriopisa chilkensis* and *Maera othonides* were quite common. To study the preference, 4 each of these prey species were introduced into beakers each containing 1 prawn of the same weight range (av. 0.44 g).

A. chilkensis was always preferred by the prawn while the other species were less preferred probably because of their greater ability to escape the predator. In order to ascertain preference for live and freshly killed ones the experiment was repeated using live and killed species as food. Since *E. chilkensis* is fairly large one each of large, medium and small sized individuals with average length (mm)/weight (g) of 15.2/0.026, 8.0/0.012 and 3.5/0.0027 respectively were introduced into the beakers instead of the same size. Again a marked preference for *A. chilkensis* was shown by the prawn although no distinction between live and the killed ones was noticed. None of the live amphipods were eaten, but among the killed ones all of *E. chilkensis* were eaten although only one of *M. othonides* was eaten indicating preference for *E. chilkensis* which is larger and more fleshy. *M. othonides* is the least preferred. However, when they were given alone to 2 day starved prawns, they were found actively sought by the predator.

An interesting observation made during this study was that *Apseudes gymnophobia*, a species of the family Tanaidaceae, which made its first appearance in the sampling locality by the middle of March was always avoided by the prawn.

Satiation limit—Twelve prawns of 4 different weight ranges starved for 2 days were selected and given unlimited number of *A. chilkensis*. All prawns ate at a faster rate initially and many of them continued to feed even after 2 hr (Table 1). Active prawns did not stop feeding. Although one large prawn (0.9 g) consumed as many as 38 of *A. chilkensis*, weighing about 0.093 g, in 3½ hr many smaller prawns (0.38-0.45 g) also consumed 24 to 30 of *A. chilkensis* during the same period. In another experiment lasting 5 hr with 6 individuals (0.42 to 0.65 g), one prawn was sluggish and consumed 16½ prey animals in the first 2¼ hr, stopped further feeding and moulted after another 2 hr. The remaining 5 prawns consumed between 37 and 41 tanaidaceans.

Effect of water depth on feeding rate—The study was made using the 3 prey species in 4.25 l rectangular jars with 10, 20 and 30 cm of water. The depth of water does not seem to have any appreciable effect on the preying efficiency. This is mainly because prawns were most often seen to catch the prey only from the bottom.

Effect of mud on preying efficiency—To study the effect of mud on the preying efficiency of prawns of different size groups, 0 to 40 ml mud was added in different beakers to give a depth of 0 to 1.4 cm. Clean fine sand, sieved through 0.062 mm mesh, was also used to study the effect. Preying efficiency decreased with increase in the quantity of mud irrespective of the size range of the prawns (Table 2). This is further corroborated by the analysis of variance which gave highly significant variance ratio ($P<0.001$) for mud although between trials variation was significant at 5% level for the larger size group. Statistical analysis of the data was done only for the 2nd series since in the 1st some beakers were emptied of the prey before the experimental period.

When clean fine sand was used instead of mud the number of prey eaten in different concentrations of sand was quite random (Table 2) indicating that the feeding efficiency is independent of the concentration of the sand. Analysis of variance showed that between sand variations were not statistically significant. In order to find between which of the concentrations of mud the preying efficiency varied significantly, least significant difference (LSD) at 5% level was found and the average number of prey consumed at different mud concentrations compared. Generally feeding efficiency was not affected significantly in 5 ml of mud but was affected at 15 ml and feeding was negligible in 30 and 40 ml.

Mode of feeding—Predatory behaviour and mode of feeding on large particles in individual prawns (weight range of 0.43-0.46 and 0.76-0.82 g) were studied when a single prey or a number of them were added. Both live and freshly killed prey were tried.

Prawn even when it remained quiescent before the food was added became active soon after the introduction of the prey. Most of the prawns continued to move actively during the entire period of observation (1 hr), remaining quiet when the prey was being eaten. Feeding time was often found to be a minute or even less with *A. chilkensis* and smaller individuals of *E. chilkensis*.

When freshly killed *E. chilkensis* of different sizes were given to *M. dobsoni* (weight range of 0.33-0.54 g) the larger preys (0.026 g) were always preferred even if they could be eaten slowly. It was also noticed that the large sized *E. chilkensis* was often eaten in 2 stages.

Table 1—Satiation Limit of *M. dobsoni* Fed *A. chilkensis*

[After 2 hr observation discontinued if prawn stopped feeding for more than 20 min]

Weight of prawn (g)	Number of *A. chilkensis* eaten at every 15 min															
0.38	7	1½	2	1½	1	1	0	0	1	0						
0.38	8	2*	3	1	1	0	1	2	1	4	2	1	2	2	0	0
0.39	6	3	2	3	1	1	0	0	0	1	0	0				
0.43	7	3*	4	2	2	1	1	3	1	1	1½	1½	1	0	0	
0.44	9½	½*	4	3	2	3	0	2	0	1	1	1	3	0	0	
0.45	9½	½*	5½	2	½	1	1	1½	½	1	1	0	0			
0.53	3	4	4	3	2	1	2	1	1	0	0					
0.55	8½	½	0	0	0	1	0	0	1	0	0					
0.57	8	2*	4	3	1	3	0	1	3	1	0	0				
0.78	6	3	0	0	5	2	2	0	0							
0.83	6	4*	4	1	3	0	2	2	1	1	0	4	0	0		
0.90	7	3*	5	2	2	2	3	3	1	3	2	4	1	0	0	

*These prawns were left without prey from 3 to 13 min during the 2nd time interval

Table 2—Effect of Density of Mud and Fine Sand on the Preying Efficiency of *M. dobsoni*

Mud or sand (ml)	Mud																		Sand			
	1 day starved				2 day starved														2 day starved			
					Series I						Series II											
	(a) Trial 1		(b) Trial 2		(c) Trial 1		(d) Trial 2		(e) Trial 3		(f) Trial 1		(g) Trial 2		(h) Trial 3		(i) Trial 4		(j) Trial 1		(k) Trial 2	
	Number eaten at the end of 1 hr																					
0	4	1	2	0	5	5	5	5	5	5	5½	6½	7½	8	6	6½	9½	10	5	5	5	5
5	3	2	3	1	4	5	4	5	5	4	4	6	1	1	4	6	10	5	1	4	5	5
15	1	1	1	1	4	4	0	0	3	2	2	3	3	1	4	1½	0	4	5	4	1	0
30	1	0	0	0	3	1	1	3½	0	1	2	1	0	0	0	0	0	0	0	1	1	5
40	1	0	0	0	½	1	0	0	0	0	0	0	0	0	0	0	0	0	3	5	4	3

Average weight (g) range and number of prey, in parenthesis, given in different trials:
a, 0.36-0.54 (5); b, 0.24-0.39 (5); c, 0.3-0.67 (5); d, 0.43-0.53 (5); e, 0.41-0.56 (5); f, 0.6-0.76 (10); g, 0.56-0.78 (10); h, 0.41-0.57 (15); i, 0.4-0.55 (15); j, 0.42-0.92 (6); and k, 0.4-0.79 (6)

A. chilkensis was quite sluggish and seldom able to escape the prawn although this was not so with the amphipods. *M. othonides* was the most agile of the 3 species and was only occasionally caught. The medium and small sized *E. chilkensis* [av. length (mm)/weight (g) of 8/0.012 and 3.5/0.0027 respectively] could be caught only with considerable effort.

The present results indicate that when amphipods or tanaidaceans were given as food, *A. chilkensis*, which was dominant in sampling locality was highly preferred as food by *M. dobsoni*. George[1] points out that in the gut contents of *M. monoceros* from the Cochin backwater, 40.56% of the crustacean remains were of amphipods and tanaidaceans indicating that they form a substantial part of their diet. However, the present study indicates that in a muddy sand substratum all these organisms probably do not become available for predation owing to the presence of silt and clay. Such areas being their natural habitat, prawns have to make up this deficiency by relying on detritus and probably also on algal populations, dead and decaying organisms, etc.[2]. Studies on satiation limit show that many prawns feed almost continuously on *A. chilkensis* during the entire period of observation. It may be that the amphipods are often able to escape the predator that they are not preyed. Hence it may not be appropriate to treat prawns as obligate detritus feeders or even as obligate omnivorous scavangers even if detritus often forms a considerable portion of their gut contents. They are more carnivorous than they are assumed to be.

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Diel Variations of Zooplankton at Kavaratti Atoll (Lakshadweep)—S.C. Goswami, National Institute of Oceanography, Dona Paula, Goa 403004

Zooplankton Abundance in the Laccadive Sea (Lakshadweep)—S.C. Goswami, National Institute of Oceanography, Dona Paula, Goa 403004

Further Observations on Gaveshani Bank—S.Z. Qasim, National Institute of Oceanography, Dona Paula, Goa 403004

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The Laccadive Sea (Lakshadweep)

INTRODUCTION

The union territory of India named as Lakshadweep (Laccadives) includes a group of coral islands and banks in the southeastern Arabian Sea, 100 to 250 km from the west coast of India. In all, there are 21 islands and banks of which 11 are inhabited. All the inhabited islands are atolls and each atoll is oriented along a north-south axis, with its island on the east and coral reef on the west. These islands and banks collectively form the Laccadive Archipelago or Lakshadweep.

The sea around these islands, demarcated by 8° and 14°N parallels and 71°30′ and 74°E meridians and occupying an area of about 2.3×10^5 km^2, has been identified as the Laccadive Sea.

The entire Archipelago is of considerable scientific interest, but unfortunately not many studies have been made earlier. The first comprehensive study of the fauna of this area was made by J Stanley Gardiner (1903-1906) and the results were published in 2 volumes under the title *The Fauna and Geography of the Maldive and Laccadive Archipelagoes* (Cambridge University Press). After this pioneering work no investigation on this area was carried out till the late 1950s when the fishing vessel *Kalava* made a few short cruises to some of the islands. Subsequently, some more studies were carried out by the National Institute of Oceanography on some of the atolls and lagoons of Lakshadweep making use of the passenger cum cargo ships plying between the mainland and the islands.

The first organized effort made by the National Institute of Oceanography was during the 31st cruise of *R V Gaveshani* to the Laccadive Sea in March-April 1978, though the research vessel had visited the Laccadive Sea twice during 1976 as part of the 10th and 13th cruises in the Arabian Sea. The 31st cruise was exclusively undertaken to make some oceanographic studies on the Laccadive Sea. A team of 19 scientists and technicians worked in the area from 20 March to 6 April 1978 covering 2645 line kilometres and occupying 30 stations.

During the cruise, water and plankton samples were collected at all the stations using Nansen reversing bottles, large van Dorn water samplers, Indian Ocean standard net, Heron-Tranter net and Neuston net. Bathythermograph, thermosalinograph and a shipborne wave recorder were run at all the stations and conductivity-temperature-depth recorder (CTD) was operated at selected stations. Routine meteorological observations were made at all the stations.

In all, 347 water samples were analysed on board for salinity, dissolved oxygen, *p*H, phosphate-phosphorus, nitrate-nitrogen, nitrite-nitrogen, ammonia-nitrogen, total nitrogen, silicate-silicon and fluoride. Many samples were filtered on board for the estimation of heavy metals, extracellular products, particulate organic carbon, dissolved glycollic acid and glycollates, chlorophyll and detritus. All these samples were preserved on board for further analysis in the laboratory. Moreover, 82 samples were inoculated with ^{14}C and incubated on board for the study of photosynthetic productivity. In all, 93 zooplankton samples were preserved on board for subsequent examination of biomass, secondary production, species composition, etc.

In the Laccadive Sea the water masses observed were Arabian Sea Surface, Red Sea and North Indian Ocean Deep. The surface salinity increased from south (8°30′N lat.) to north (12°N lat.) while the surface temperature decreased from coast to offshore and also from south to north. The mixed layer extended up to 90-100 m depth with a 2 layered structure, an upper isothermal and a lower with weak thermal gradients. The predominant significant wave height and zero-crossing period for March/April were 50 to 70 cm and 8 to 8.5 sec respectively.

Upwelling, induced by wind stress and Coriolis Force, seems to transport nutrient-rich water to the surface in the vicinity of the islands. Variations in nutrients in surface layers suggest that their uptake is largely regulated by phytoplankton production. Two oxygen minima at 200 and 500 m were observed south of 11°N. Absence of nitrate-nitrogen, which seems to act as a limiting factor in phytoplankton production, and 0.5 μg at/litre phosphate-phosphorus were observed in the first 75 m. High magnesium and low fluoride concentrations were observed. The concentration of calcium was much lower inside the lagoon than in the open sea, which may be due to the biological precipitation of $CaCO_3$.

In this region the primary production was 372 mg C/m^2 with mean column chlorophyll value 4.9 mg/m^2

and particulate organic carbon 3.61 g/m^2. The extracellular production varied from 0 to 3 mg/m^3/hr representing 0 to 75% of the total carbon-dioxide assimilation. Detritus contributes about 95% of the total particulate matter, while the contribution of phytoplankton and zooplankton in the suspended matter was very low. The bacterial biomass was 15.92×10^8 μg carbon and the population density had 2 maxima, one at the surface and the other at 500 m depth. Zooplankton studies indicated unusual abundance of gravid females of red bathypelagic prawn *Acanthepyra sanguinea.*

The results of various parameters studied during the 31st cruise are elaborated in the papers that follow. For comparison some of the data collected from the Laccadive Sea during the earlier cruises (10th and 13th) in 1976 were also incorporated.

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Physical Characteristics of the Laccadive Sea (Lakshadweep)

M J VARKEY, V KESAVA DAS & D V RAMA RAJU
National Institute of Oceanography, Dona Paula, Goa 403 004

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Several physical properties of the Laccadive Sea were studied based on data collected in March/April and the results compared with the data earlier obtained from the same area during October and December. The mixed layer extended to 90-100 m depth with a 2-layered structure, an upper isothermal and a lower with weak thermal gradients. The Arabian Sea High salinity water was observed as a sub-surface high salinity core in the Laccadive Sea. Persian Gulf and Red Sea waters were also observed. Surface salinity showed wide variations which were related to the influx of water from the Bay of Bengal Considerable meridional salinity gradients existed at the surface.

During the 31st cruise (20 March to 6 April 1978) of *R V Gaveshani* the Laccadive Sea area (Fig. 1) has been studied because of its geographical position[1] and features which influence the movement of water masses[2,3]. The coral islands and shallow banks in this area would possibly promote eddy formations of large dimensions[4,5]. Further, these eddies may introduce spatial changes in the structure of oceanic processes at mesoscale[6].

Methods

Standard hydrographic casts were taken for the collection of temperature and salinity data. Salinity samples were analysed on a precision ($\pm 0.003^{\circ}/_{oo}$) laboratory salinometer. Bathythermograph dips were taken at 29 stations. Continuous records of surface salinity were collected, and records read at 5 min intervals, using a thermo-salinograph along some runs (Fig. 1). The values were compared with those obtained with a precision laboratory salinometer and the necessary corrections made. In addition, surface meteorological observations were carried out at all the stations.

Temperature and salinity data were utilised for studying the distribution of water masses. The variations in the mixed layer were studied from the bathythermograph records.

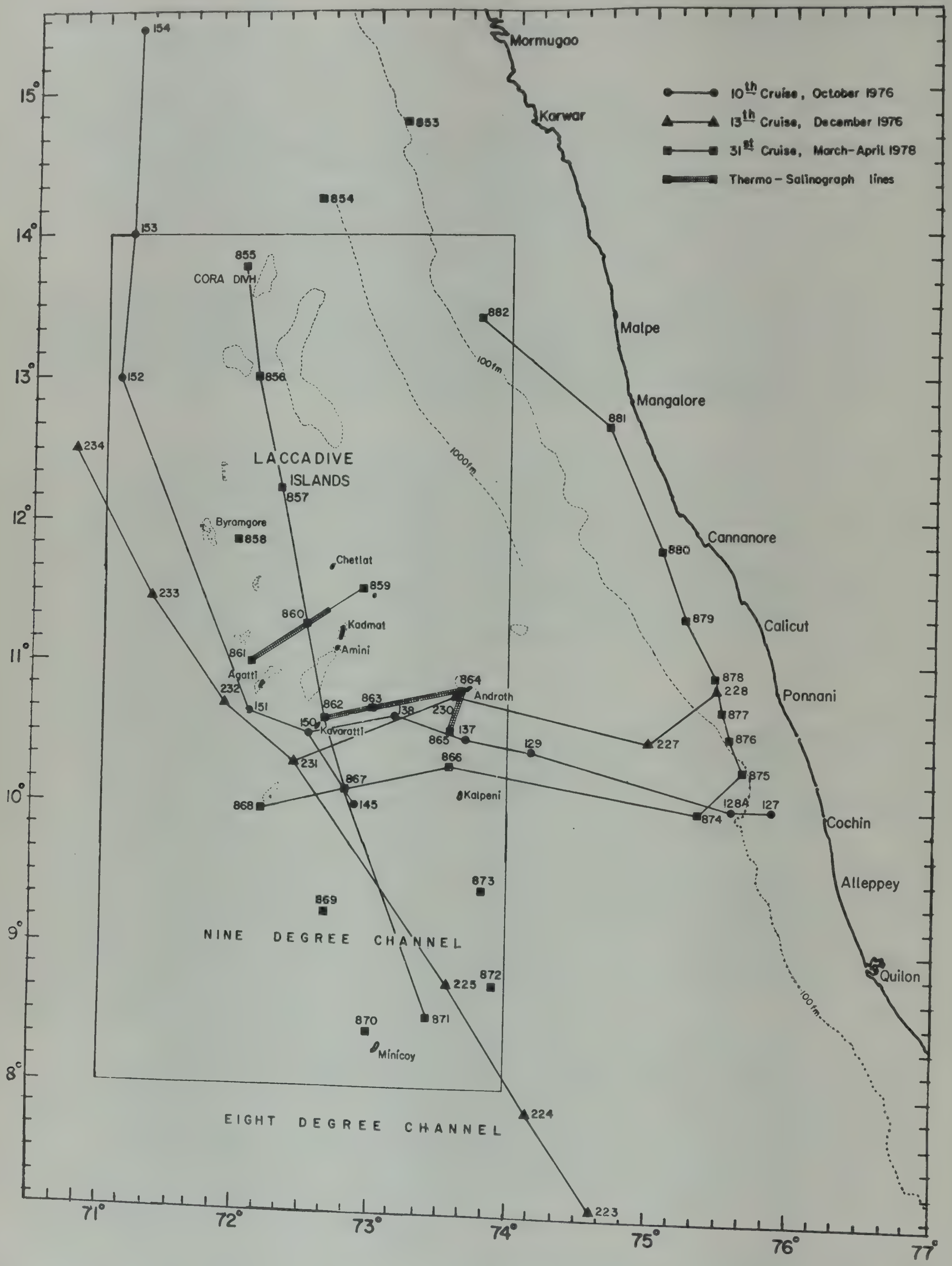
Data collected during the 31st cruise were compared with those collected during the 10th (October 1976) and 13th (December 1976) cruises[7] of *R V Gaveshani* to determine variability in the area.

Results and Discussion

Temperature and mixed layer—Vertical distribution of temperature along the 3 sections is given in Figs 2a and 3a. In general, the surface temperature decreased towards offshore and also from south to north. The upper 50 m layer was almost isothermal in the deep water sections. This feature was observed earlier, by Jayaraman *et al.*[8] in April. The top of thermocline was generally found between 90 to 100 m depth in the vertical section. Between the thermocline and the upper isothermal layer, a layer with weak temperature gradients (0.02-0.06°C/m) was recorded. These 2 layers together form the mixed layer. This layering is considered to be the result of winter deepening of the thermocline which persists through March-April[9]. In the zonal section (Fig. 3a) the thermocline became shallow towards the coast. The thickness of the main thermocline varied between 80 and 125 m. The temperature gradient in the thermocline gradually increased from north to south (Fig. 2a, A). In general, there was a strong upslope of isotherms towards the coast (Fig. 3a) as well as towards the south (Fig. 2a, A) extending down to a depth of about 300 m. The slope was more prominent in the thermocline region in both the sections. This upsloping, may be indicative of the 'rising' of subsurface waters by surface divergences. Below 300 m also the distribution of temperature showed a weak upsloping up to 700 m in both the sections. The water column in the inner shelf was almost isothermal (Fig. 2a, B).

During October and December (see Fig. 1 for stations) the mixed layer thickness in the open sea varied between 50 and 60 m. The thickness gradually decreased as the depths decreased and in very shallow waters the water column was homogeneous up to close-bottom depths with a sudden decrease in temperature very close to the bottom off Cochin[7].

Salinity—Vertical distribution: Figs 2b and 3b present 3 vertical sections of salinity. The noteworthy feature in Fig. 2b is the spreading of the Arabian Sea


10th Cruise, October 1976
13th Cruise, December 1976
31st Cruise, March-April 1978
Thermo-Salinograph lines
Mormugao
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Malpe
Mangalore
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879
880
881
882
15°
14°
13°
12°
11°
10°
9°
8°
71°
72°
73°
74°
75°
76°
77°

Fig. 1—Station locations in different cruises

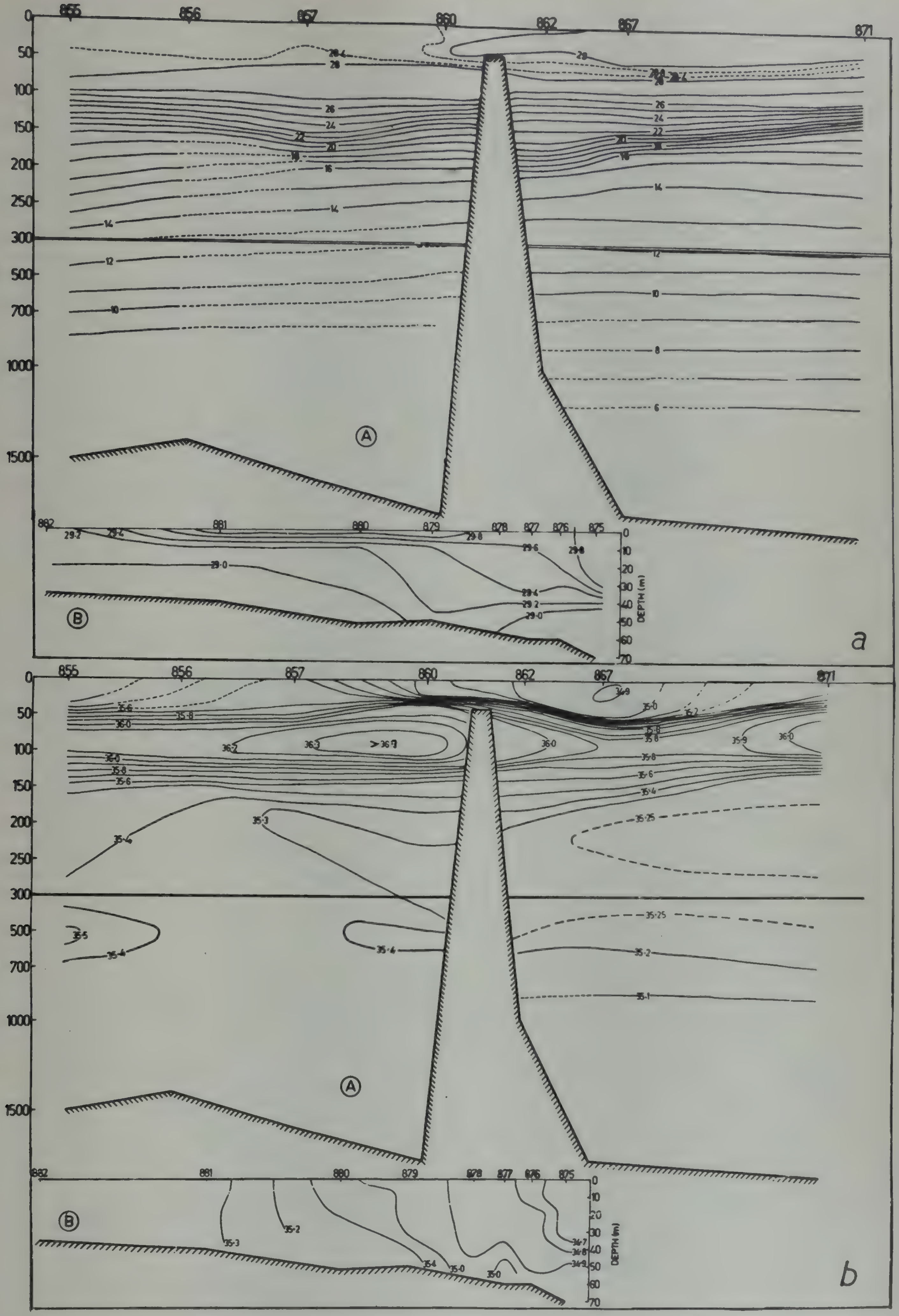

Fig. 2—Vertical distribution of temperature (a) and salinity (b) along a deep section (A) and shallow section (B)

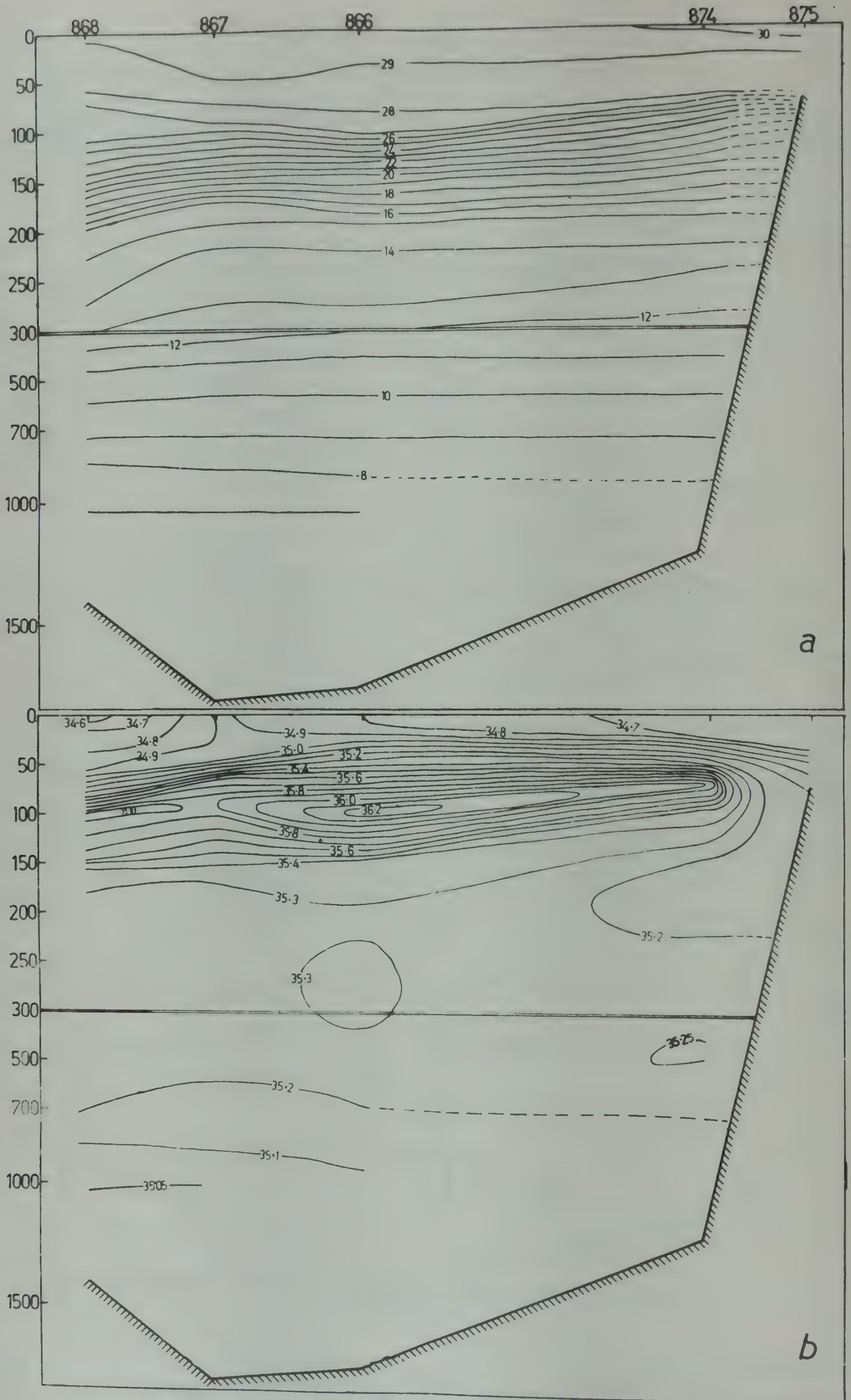

Fig. 3—Temperature (a) and salinity (b) distribution perpendicular (zonal) to the coast

high salinity water from north (st 855) to south (st 871). This high salinity water extends vertically between 30 and 150 m depths. The presence of this high salinity tongue in April was earlier reported by Jayaraman *et al.*[8]. The maximum core value observed was 36.38‰ at st 860 at 100 m. The presence of a steeply rising narrow oceanic reef (Fig. 2b, A) does not seem to affect the southward spreading due to the large width of the watermass core (Fig. 3b) compared to that of the reef. North of the reef, (Fig. 2b) high salinities (>35.4‰) were observed between 400 and 700 m indicating the presence of the Red Sea water. South of the reef, below 150 m, only low salinities (<35.3‰) were observed. Sts 867 and 871 were situated in such regions where the surface waters (see Figs 2b and 4) were distinctively different (see the bounded area surface minimum in Fig. 6). The low salinity surface water from the Bay of Bengal spreads into the Arabian Sea[9-11] in the area between these 2 stations extending down 30 to 40 m. Hence some of the near surface contours between these stations are completed by broken lines to show the unrealistic nature of the contours. The presence of low salinity surface water in the same area was earlier explained by Darbyshire[9]. St 869 (Fig. 1) situated about 60 km west of the section running north-south but almost equidistant from sts 867 and 871 (Fig. 2b, A) showed the presence of high salinities (>35.3‰) up to a depth of about 600 m (Fig. 6). St 873, also situated between 867 and 871 but towards the east (~80 km) showed low salinities (<35.3‰) below 200 m (Fig. 6). These observations indicate that east of 72°30′E and south of 11°N the cores of the Persian Gulf and Red Sea waters are much 'diffused'. Fig. 2b, B gives salinity distribution along the coast from st 875 to st 882. The water column in the inner shelf is almost isohaline with a general increase towards north. However, close to the coast, the salinity increases slightly (34.7 to 35‰) from surface to bottom; this vertial gradient progressively decreases up coast and finally disappears off north of Cannanore. The zonal section (Fig. 3b) shows the presence of Arabian Sea high salinity water all along the section with its core centred around 100 m depth.

The low salinity surface layer deepens at the east and west sides of the zonal section (Fig. 3b). The findings reveal that the Arabian Sea high salinity water is present all through the deep survey area. The absence of this high salinity water in the shelf confirms the earlier findings[12,13].

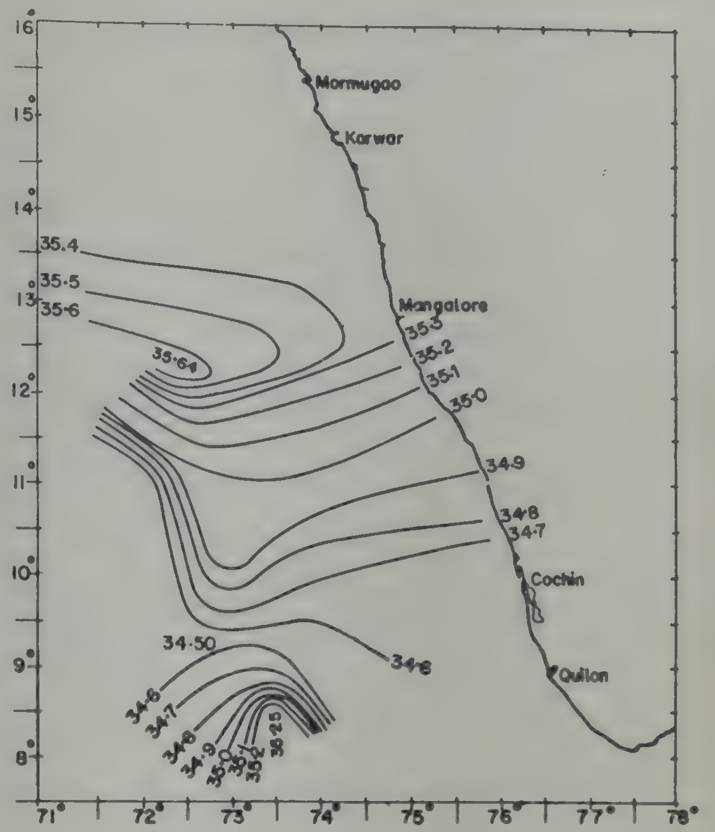

Fig. 4—Surface salinity distribution

During December also the Arabian Sea high salinity water core is continuously seen at a depth of 75 m extending zonally from st 232 to st 227 (ref. 7). But the core values gradually decrease from offshore to the shelf. Meridionally, this high salinity core is observed from the north up to st 231. The low saline surface water as observed during March (Fig. 3b), along the zonal section was not present during December. Even at st 228 (depth 45 m), the water column showed almost isohaline (35.02 to 35.08‰) nature. A comparison of the situation in December to that in March shows[7] that by December, the Bay of Bengal water has not advanced into the Arabian Sea to reach the section, off Cochin, while, by March (Fig. 4), it has spread extensively quite deep into the Arabian Sea. Similar features were noticed by Wyrtki[14] also.

Surface salinity: Surface salinity distribution is shown in Fig. 4. The presence of low saline water is very conspicuous. The source of the water is considered to be Bay of Bengal[9-11]. The Bay of Bengal low saline water enters into the Arabian Sea and spreads in a north-westerly direction[14]. Its incursion begins during November-December and attains its maximum penetration during January-February. By May-June the tongue like surface distribution fades away. In the Arabian Sea, due to surface evaporation and mixing the salinity of the low saline surface water gradually increases and by March, the lowest salinity was only 34.5‰. Along the northern boundaries, 12°N, this water gets mixed with the high saline water of the northern Arabian Sea. Its southern boundary is formed by the waters from the equatorial Indian Ocean[14]. Along the coast the salinity increases from 34.6 to 35.3‰. An earlier survey[13] showed much lower salinity (<34.3‰) off Kerala Coast. In general, in the Laccadive Sea, the surface salinity increases from south (8.5°N) to north (12°N) with a sharp increase (34.6 to 35.64‰). Similar trend was noticed earlier also[9].

Variation in the zonal surface salinity gradient west of 73°E was large meridionally and east of 73°E it was very small (see Fig. 5).

At the beginnings and the ends of the salinograph profiles (Fig. 5) the salinity values do not agree very closely with those in Fig. 4. This was due to the change in sampling positions between the timings of the hydrocast and the salinograph intake due to ship's drift. The largest difference in salinity was observed between sts 860 and 861. As can be seen from Fig. 5, these 2 stations were situated in different regions of the

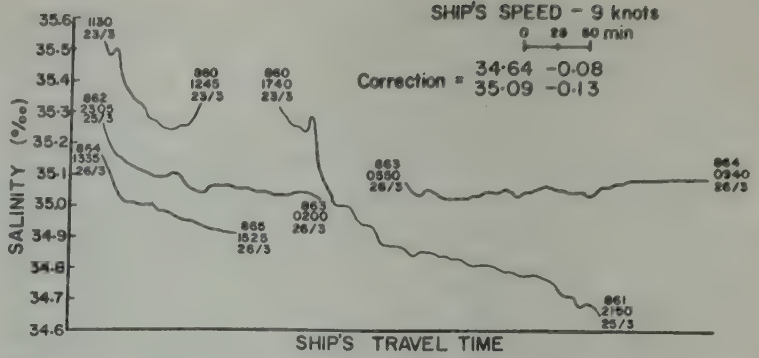

Fig. 5—Salinograph profiles collected during the 31st cruise (replotted)

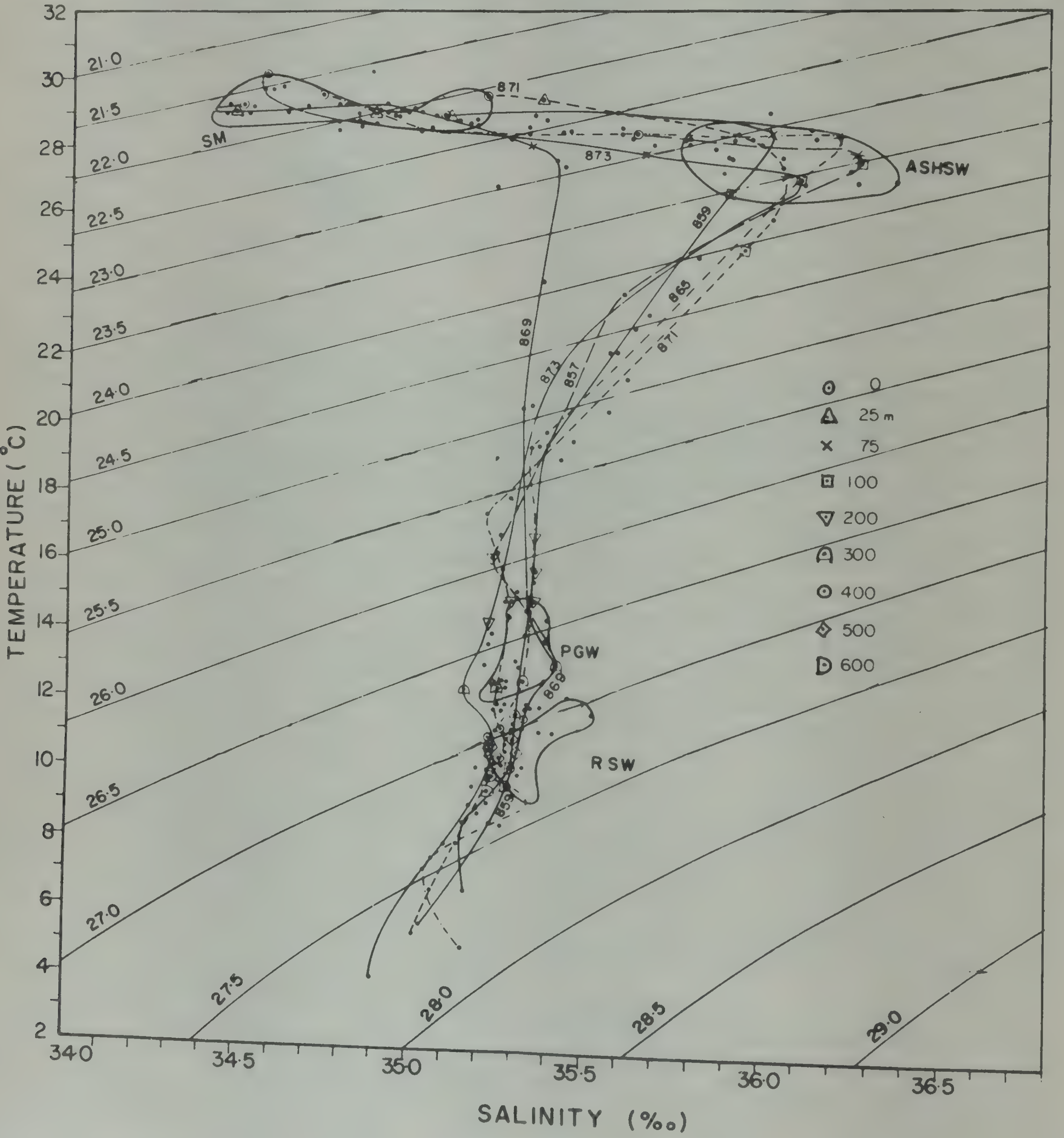

Fig. 6—T-S mapping [ASHSW, Arabian Sea high salinity water; SM surface minimum; PGW, Persian Gulf water; RSW, Red Sea water]

surface water masses; the north Arabian Sea surface water and the Bay of Bengal water. Between sts 863 and 864 the salinity profile was even. This agrees very closely with the surface salinity distribution shown in Fig. 4.

Water masses—Temperature-salinity values at the observed depths for sts 855 to 873 are given in Fig. 6. Also shown in the figure are 6 sample T-S curves from different parts of the survey area (sts 857, 859, 865, 869, 871 and 873) bringing out the wide variations in the vertical and horizontal T-S structure (see also Fig. 4). The observed core regions of salinity maxima and minima (surface layer minimum) are bounded in the same figure. At st 857, the surface water is of north Arabian Sea origin and the Arabian Sea high salinity water core is observed at 75-100 m depths (σ_t 23.5). The Persian Gulf water is observed at depths between 200 and 300 m (σ_t 26.2-26.8). St 859 is typical with high salinity (35.07$^{\circ}/_{oo}$) surface water compared to the southern coastal low saline water (34.7$^{\circ}/_{oo}$), extending up to a depth of about 30 m and of northern Arabian Sea origin. The Arabian Sea high salinity water mass is observed at about 75 m depth with a core value of 36.03$^{\circ}/_{oo}$ (σ_t22.8-23.8). At st 865, the surface layer has a salinity of 34.73$^{\circ}/_{oo}$ and this layer extends to a depth of about 20 m. St 869 is characterised by very low surface salinity (34.5$^{\circ}/_{oo}$) and this layer of surface water is seen up to a depth of about 25 m. The Arabian Sea high salinity water core is conspicuously 'absent' or 'diffused' at this station. Persian Gulf and Red Sea waters are identifiable at this station. At st 871 the surface salinity is 35.25$^{\circ}/_{oo}$ and this layer extends to a depth of about 20 m. This surface water spreads into the area from the southern latitudes[14] and the low saline surface water of the Laccadive Sea envelopes it around the northern boundaries (see also Fig. 4). The Arabian Sea high salinity water is observed around 75 m (σ_t 23.4). Persian Gulf and Red Sea waters are traceable at this southern most station but the salinity values are 35.29 and 35.28$^{\circ}/_{oo}$ respectively.

The Arabian Sea high salinity water is present all over the deep Laccadive Sea in the layer 50-150 m, as a distinct high salinity water mass (σ_t 22.8 to 23.8). The high salinity core lies in shallower depths in the northern region. As the water spreads down south, the core deepens. Similar features were observed during the 16th cruise of *R V Gaveshani* along a section more closer to the shelf[13]. Fig. 7 gives an idea of the spreading of this water mass. Whenever the salinity values appear low the core is situated below 75 m. At st 868 the Arabian Sea high salinity water layer (35.3$^{\circ}/_{oo}$) starts abruptly at a depth of 85 m; hence very low salinity (35.24$^{\circ}/_{oo}$) is obtained at 75 m (Fig. 7). A noteworthy feature of the Arabian Sea high salinity water core is its high vertical gradients and narrow vertical extensions. The core of this water mass extends down into the thermocline from the isothermal layer.

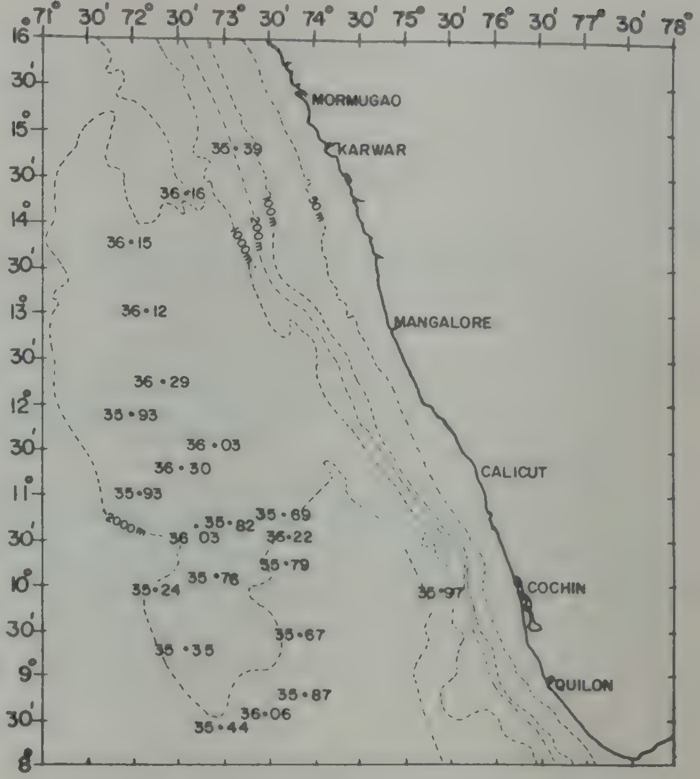

Fig. 7—Salinity distribution at 75 m level

CSTD records collected at sts 868, 870, 872 and 873 show that the core of Arabian Sea high salinity water is 70 to 80 m thick and the core depth differs from station to station. The large variations in salinity at 75 m (Fig. 7) is due to sharp gradients and variations in the core depth. At st 869, the core is not clear and the maximum salinity observed in the layer 100 to 150 m is only 35.41$^{\circ}/_{oo}$. Yet the 'diffused' core might have existed between 100 and 150 m. A comparison with the CSTD record from st 870 (maximum core value 35.7$^{\circ}/_{oo}$) brings out the possibility of similar situations existing at sts 869 and 870. Whereas, at the nearby sts 868, 871, 872 and 873 the core values were > 36.1$^{\circ}/_{oo}$. This observation indicates a westward boundary for the core west of sts 869 and 870. Darbyshire[9] observed a high salinity core at about 90 m, along 72°E with salinities between 35.5 and 35.75$^{\circ}/_{oo}$. This may be the 'diffused' western side lobes of the Arabian Sea high salinity water tongues spreading south from the northern Arabian Sea as observed in the present study. Persian Gulf water was present at most of the stations around 250-300 m only as a mild high salinity core between σ_t 26.2 and 26.8. Red Sea water was observed in the layer around 500 m between σ_t 27 and 27.4.

In the Laccadive Sea below the typical water masses of the Arabian Sea (below ~ 600 m) the T-S structures show the trend (Fig. 6) of gradual decrease. At these depths the high salinity water masses mix with the low saline intermediate waters which rise to shallower depths and the resulting salinity structure shows much complexity[15].

Acknowledgement

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Wave Characteristics of the Laccadive Sea (Lakshadweep)

V KESAVA DAS, M J VARKEY & D V RAMA RAJU
National Institute of Oceanography, Dona Paula, Goa 403 004

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Waves in the Laccadive Sea were recorded during March-April 1978 (31st cruise of *R V Gaveshani*) using a ship-borne wave recorder. Zero-crossing period, significant wave height and spectral width parameter were determined and their distributions studied. Predominant significant wave height and zero-crossing period were 50 to 70 cm and 8 to 8.5 sec respectively. Seasonal variations in the wave characteristics for the area were also studied using the historical data reported by the ships. The predominant wave periods and wave heights were 5-6 sec and 0.5 to 1.5 m respectively during the fair weather season (October-May) and 5-9 sec and 1-3 m respectively during the rough weather season (June-September). A wide range of wave heights 0.5-5 m occurred during the rough season.

Information on wave characteristics in the offshore regions is required for navigation, offshore engineering works, etc. There is no published work of the recorded wave data from the Laccadive area. There are few studies conducted earlier on waves at certain coastal stations on the west coast of India[1-4]. The only data available on the waves for the offshore regions in the Arabian Sea are visual observations reported by ships. Studies on the wave characteristics of this area are of much importance because of the presence of several inhabited islands (atolls).

The present study is mainly based on the wave data recorded during March-April 1978 (31st cruise of *R V Gaveshani*). In addition, the wave data reported earlier by ships are also used to present a picture of wave climate of the region.

Methods

Waves were recorded at 29 stations (Fig. 1) using a ship-borne wave recorder (IOS, Model 5254; Institute of Oceanographic Sciences, UK). At each station recording was done continuously for a minimum period of 15 min. At certain stations more than one record were obtained. In total, 45 records were collected. Only 10 min records were taken, and analysis was done following the method suggested by Draper[5]. Height of the highest crest (A) and depth of the lowest trough (C) from the mean water line drawn visually, number of upward zero-crossings (N_z) and number of crests (N_c) were measured from each record.

The following parameters were then computed from the above measurements. The height of the highest wave was computed as $H = A + C$ and corrected for pressure attenuation and the instrument's response, finally giving H_1. The other parameters computed were the significant wave height (H_s), mean zero-crossing period (T_z) mean crest period (T_c), and spectral width parameter (ε).

The data were then grouped for further analysis, as there were no marked changes in the weather pattern during the cruise. Direction of the waves was observed visually, at a few stations.

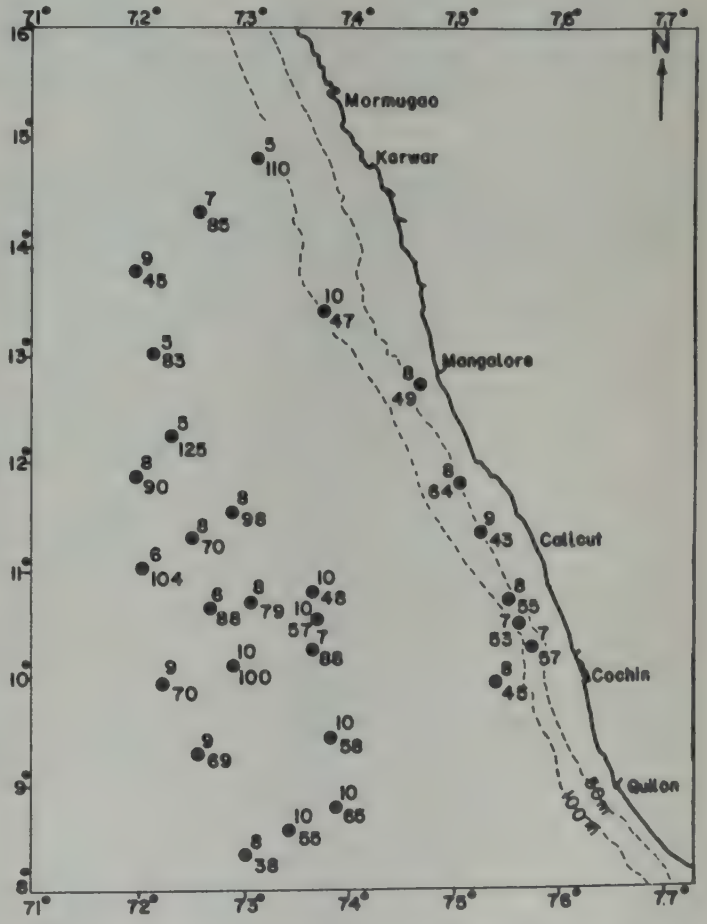


Fig. 1—Station-wise distribution of zero-crossing period (sec; upper number) and significant wave height (cm; lower number)

Results and Discussion

Fig. 1 shows T_z and H_s at each station. At those stations where more than one record were available, the maximum observed values of T_z and H_s were given. Generally low H_s were observed along the coast.

Fig. 2a gives the percentage occurrence of H_s. The predominant range of H_s was between 50 and 70 cm. The maximum H_s was 1.25 m. The highest recorded H_1 was 2 m with a T_z of 5.2 sec. Fig. 2b gives the percentage occurrence of T_z. The most prominent group of T_z was from 8 to 8.5 sec with a percentage occurrence of 17. Distribution of percentage frequency showed that about 93% of the waves cover a range of period 5 to 10 sec. The maximum T_z observed was 10.2 sec.

Fig. 3a shows the distribution of ε. The modal class was observed to be 0.8 to 0.85 and the range was between 0.7 and 0.95. As all the values of ε were close to unity, it can be concluded that during the periods of observation, the wave components covered a wide range of frequencies, i.e. long waves carry short waves on top of them[5]. In other words the local sea conditions were super-imposed on light swells. Fig. 3b gives the scatter diagram showing the inter-relationship between H_s and T_z. The most common situation with H_s 50-60 cm and T_z 7.5-8.5 sec had a percentage of occurrence about eleven (111 per thousand). The scatter was wide, showing the occurrence of waves over a wide range of frequencies and heights. The highest waves were associated with shorter periods showing the dominance of local seas.

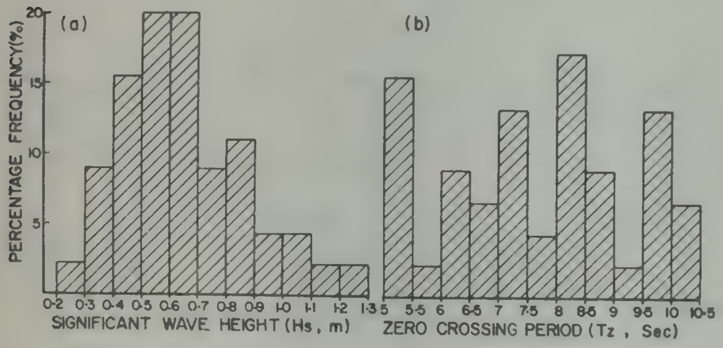


Fig. 2—Distribution of (a) significant wave height and (b) zero-crossing period

The directions of waves observed at limited number of stations, were between 330° and 360° N. This is in accordance with the wind direction and is also in agreement with the observations reported by ships (Table 1).

The distributions were compared with the other studies carried out at coastal stations along the west coast of India during fair-weather season (Table 2). Long period swells were predominant off Thumba and Mangalore as compared to the other places.

Distributions of wave parameters show that these were characteristic of the fair weather season, and were in accordance with the wind system of the season.

Wave climate—To give a picture of the wave climate in the region, the wave data reported by ships and published in the Indian Daily Weather Reports were

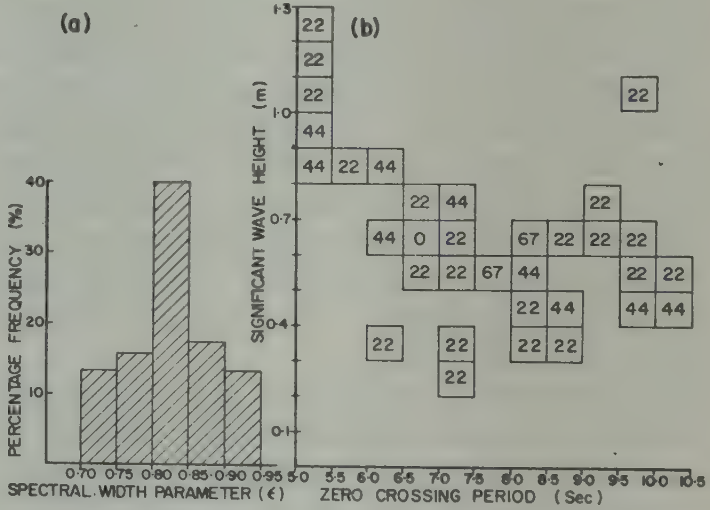


Fig. 3—Distribution of spectral width parameter (a) and scatter diagram (b) [Number in the square represents the number of occurrences of waves (parts per thousand) in a particular period-height group]

Table 1—Percentage Occurrence of Waves from Different Directions

Direction*	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.
30°	1.6	13.3	15.8	15.9	8.7	—	—	—	—	—	—	—
60°	—	5.4	9.8	8.6	8.7	—	—	—	—	—	—	—
90°	1	3.6	10.8	2	2	—	—	—	—	—	—	—
120°	3.1	7.3	4.3	4.6	2	—	—	—	—	—	—	—
150°	5.8	5.4	4.3	2	—	—	—	—	—	—	—	—
180°	15.7	9.7	2.4	—	3.4	—	—	—	—	—	—	2.5
210°	9.9	5.5	2.4	—	—	—	—	5.2	1.2	0.8	3.1	1
240°	11	3.6	—	1.3	—	—	—	7	5.4	5	7.1	6.5
270°	13.6	—	—	—	2	—	—	12.9	25	24.7	18.2	15.9
300°	12.6	9.1	3.7	8.6	12.1	—	9.2	25.2	40.7	51.7	51.1	35.8
330°	18.3	19.4	20.7	28.5	34.9	18.2	31.6	23.9	15	13.5	18.7	30.3
360°	7.3	17	25	27	26.2	45.3	39.8	23.2	3.3	3.5	—	6.5
						36.5	19.4	2.6	0.8	—	—	1.5

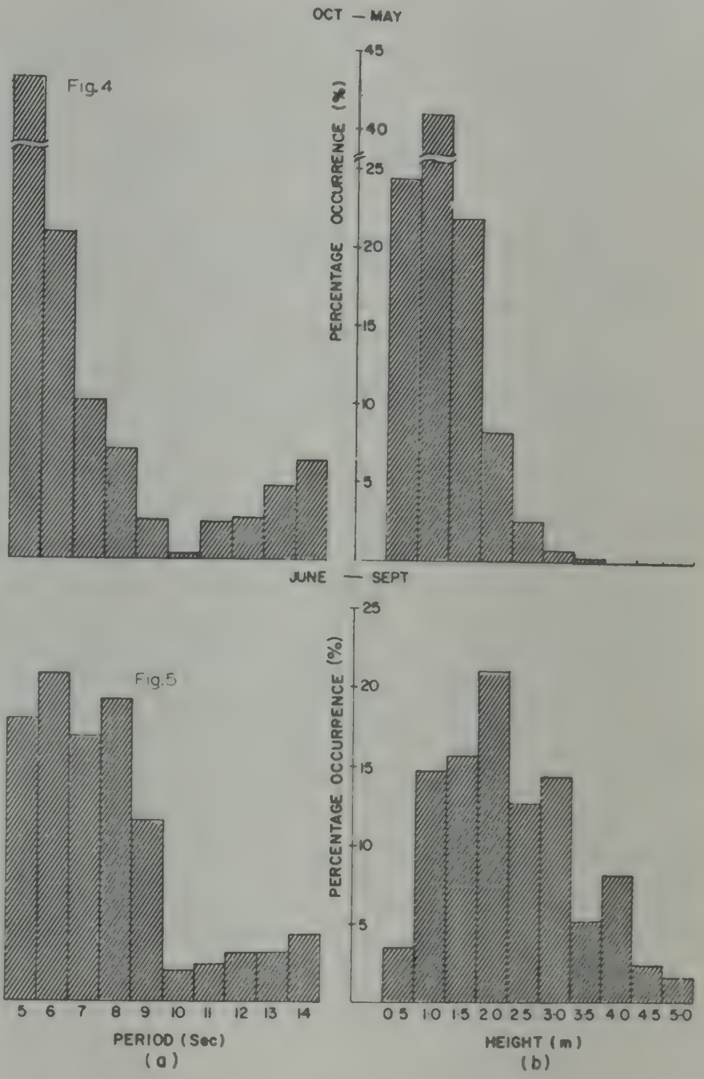
*Clockwise from the north

collected for a 5° grid between 10-15°N and 70-75°E for a period of 6 yr (1968-1973). The swell characteristics were compiled directionwise for each month. A preliminary study on the compiled data showed that the wave characteristics varied largely only between the 2 seasons, i.e. October to May (fair weather season) and June to September (rough weather season). Hence, the wave characteristics for these 2 seasons are presented separately only season-wise (Figs. 4 and 5). Percentage frequency of waves occurring in different directions are given for each month separately in Table 1. Although the table shows some changes in the directional pattern, scrutiny of the monthly data (available with authors) suggested that the characteristics (period and height) were largely the same from October to May and similarly from June to September.

The predominant direction of waves from October to May was 330° (N-NW) and from June to September 270° (W) (Table 1). The transition months appeared to be May and October when the direction changes. The directions of secondary dominance were 360° (N) from October to May and 240° (W-SW) from June to September.

Fig. 4 gives the distribution of wave periods and heights for the fair weather season (October-May). The predominant wave period was 5 sec in this season (Fig. 4a). About 80% of the waves had periods ranging between 5-8 sec (Fig. 4a). The predominant height was 1 m with a percentage frequency of nearly 41 (Fig. 4b). Almost 88% of the waves seem to occur within the range of 0.5 to 1.5 m height.

Percentage occurrences of wave period and height for the rough weather season (June-Sept.) are presented in Figs 5a and b. About 86% of the waves occurred with periods ranging between 5 and 9 sec. The distribution was almost even within the range of 5 to 8 sec, though the 6 sec period had the highest frequency of occurrence (Fig. 5a). During this season, the



Figs 4 and 5—Distribution of percentage occurrence of (a) period and (b) height during October-May (4) and June-September (5)

Table 2—Ranges and Modes of Distribution of Periods and Heights Recorded at Different Locations

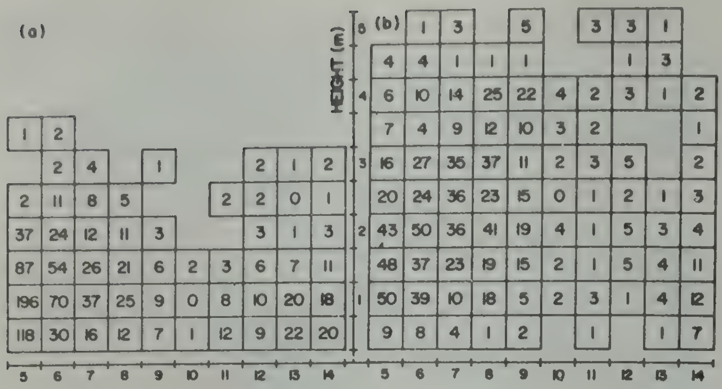
Location	Period of observation	Zero-crossing period (T_z sec)		Wave height (m)	
		Range	Mode	Range	Mode
Off Mangalore[1]	Oct-May 1968-69	7-15	11-12	0.2-1.4 (H_{max})	0.4-0.5 (H_{max})
Off Thumba[4]	April-May 1976 Oct-March 1976-77	6-15	10-12	0.3-0.8 (H_s)	0.5-0.6 (H_s)
Off Goa[3]	Nov-May 1973-74	5-14	6-7	0.14-0.77 (H_s)	0.4-0.5 (H_s)
Lakshadweep Sea*	March-April 1978	5-10.5	6-8.5	0.2-1.3 (H_s) 0.4-2 (H_1)	0.5-0.7 (H_s) 0.8-0.9 (H_1)

*Present study

H_{max} = maximum wave height in a recording interval

H_s = significant wave height

H_1 = corrected H



(a)

	5	6	7	8	9	10	11	12	13	14
	1	2								
		2	4		1			2	1	2
	2	11	8	5			2	2	0	1
	37	24	12	11	3			3	1	3
	87	54	26	21	6	2	3	6	7	11
	196	70	37	25	9	0	8	10	20	18
	118	30	16	12	7	1	12	9	22	20

(b)

	5	6	7	8	9	10	11	12	13	14
		1	3		5		3	3	1	
	4	4	1	1	1			1	3	
4	6	10	14	25	22	4	2	3	1	2
	7	4	9	12	10	3	2			1
3	16	27	35	37	11	2	3	5		2
	20	24	36	23	15	0	1	2	1	3
2	43	50	36	41	19	4	1	5	3	4
	48	37	23	19	15	2	1	5	4	11
1	50	39	10	18	5	2	3	1	4	12
	9	8	4	1	2		1		1	7

Fig. 6—Scatter diagrams for (a) fair weather season (October-May) and (b) rough weather season (June-September) [Number in the square represents frequency of occurrence of waves (per thousand) of same period and height]

predominant height seems to be 2 m with a percentage occurrence of about 21 (Fig. 5b). Nearly 80% of the waves occurred within the range of 1 to 3 m, though the range was fairly wide between 0.5 and 5 m.

Scatter diagrams relating period to height for fair weather season and rough weather season are presented in Figs 6a and 6b respectively. In the fair weather season (Fig. 6a) the most frequently occurring wave group was of period 5 sec and height 1 m (196 per thousand). In rough weather season (Fig. 6b) 2 groups of waves with period-height relationships 5 sec-1 m and 6sec-2 m were predominant and occurred 50 per thousand or 5% of the time. A comparison of the scatter diagram of recorded waves (Fig. 3b) during March-April with that of fair weather season from historical data (Fig. 6a) seem to be difficult in respect of the predominant period-height group. This is because the recorded data were limited to very short duration whereas the historical data were for the full season covering a period of 6 yr.

Comparison of wave characteristics between the 2 seasons revealed the following features. In the fair weather season, waves have predominantly shorter periods (5-6 sec) whereas in the rough weather season their predominant periods range between 5 and 9 sec. Distribution of height shows a wider range in rough weather with predominance of higher values as compared to those in the fair weather season.

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Chemical Oceanography of the Arabian Sea: Part IV—Laccadive Sea

R SEN GUPTA, CAROLINE MORAES, T W KUREISHY, V N SANKARANARAYANAN, T K JANA,
S W A NAQVI & M D RAJAGOPAL
National Institute of Oceanography, Dona Paula, Goa 403 004

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Data collected during the 10th (October 1976) and 31st (March-April 1978) cruises of *RV Gaveshani* suggest that water movements, considered typical of island-arc regions, are responsible for high levels of productivity observed in the Laccadive Sea. Patterns of distribution of nutrients and nutrients-oxygen relationships are similar to those observed in other parts of the Arabian Sea. High magnesium and low fluoride concentrations in the water indicate probable loss of the latter as insoluble ion-pairs and as apatites.

Detailed oceanographic studies of the Laccadive Sea have not been made, although isolated studies have been made on hydrography, chemistry and biology of the waters[1-7]. In the present paper, data on the chemical characteristics of the waters are given, which facilitate comparison with other parts of the Arabian Sea, with special reference to factors influencing marine productivity. Data collected during the 10th (October 1976) and 31st (March-April 1978) cruises of *RV Gaveshani* are presented here.

Materials and Methods

Water samples were collected from standard hydrographic casts using transparent TPN samplers (Hydro Bios, Kiel, FRG) and metallic Nansen bottles up to a depth of 2000 m from stations shown in Fig. 1.

Temperature, salinity, dissolved oxygen, PO_4^{3-}-P, NO_3^--N, NO_2^--N, NH_4^+-N, SiO_3-Si and F^- were measured. Temperature was read off reversing thermometers, oxygen and nutrients were measured using standard analytical methods[8]. Fluoride was analysed by the lanthanum alizarine complexone method[9].

Results and Discussion

Hydrographical characteristics around Laccadive islands—Inter-atoll variations in the depths of the isopycnal layers between (i) Kavaratti and Androth (Fig. 2A), (ii) Androth and Kalpeni (Fig. 2B), and (iii) Kalpeni and Suheli Par (Fig. 2C) were studied. Similar variations along a north-south transect between 13°45′ and 8°30′N (Fig. 2D) were also investigated.

In Fig. 2A, σ_t values from 22.5 to 23.5 show westward upsloping. At $\sigma_t > 24$, there is downsloping. The values from 26.5 to 27.1 increase with depth from east to west. In Fig. 2B, except σ_t 22, all the other isopycnals slope towards the north. In Fig. 2C, σ_t values from 22 to 23.5 show westward upsloping. Below these, up to σ_t 26.5 the upsloping is eastward. The values between 27 and

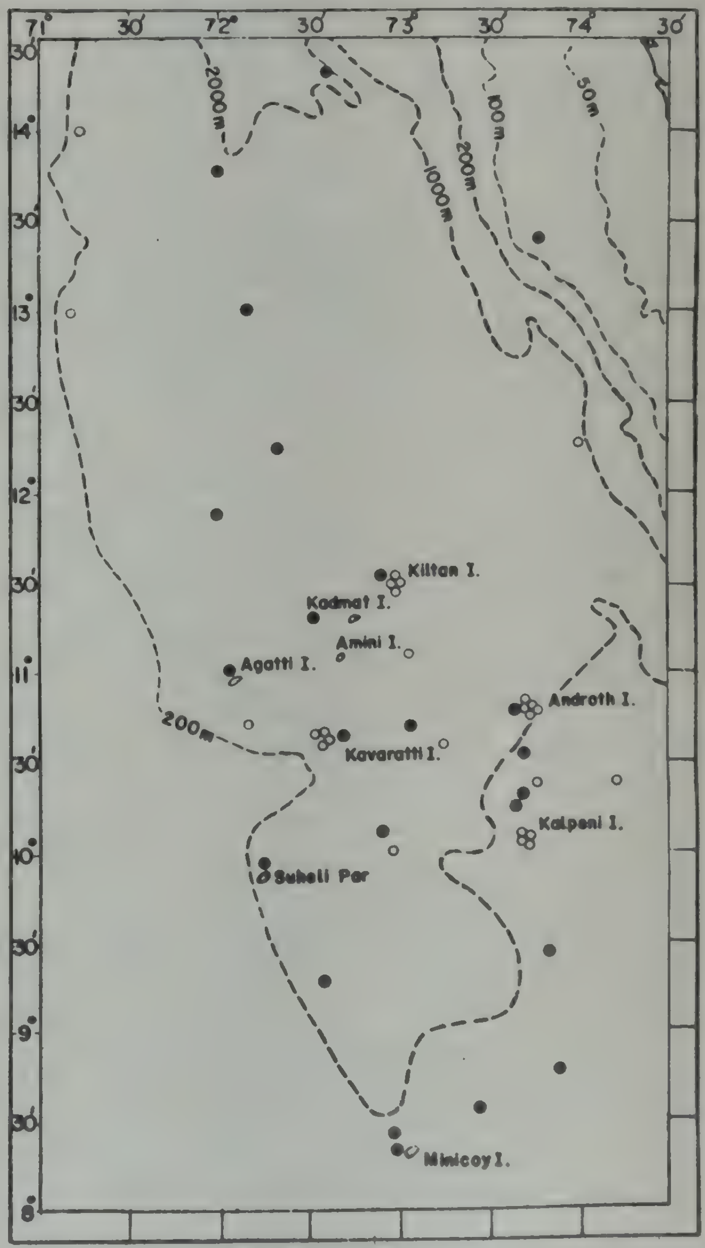

Fig. 1—Observation stations (O, 10th cruise and ●, 31st cruise)

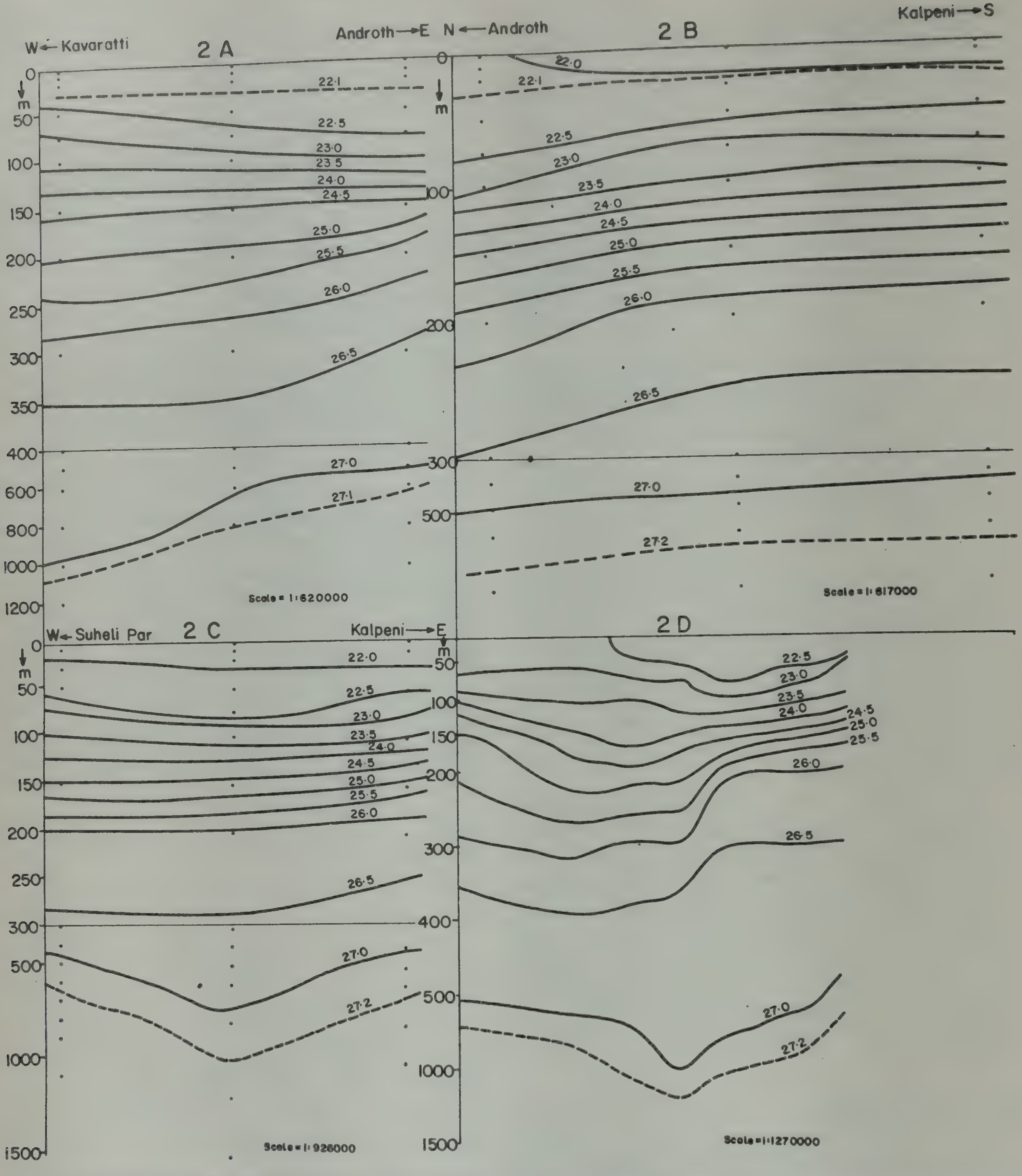

Fig. 2—Isopycnals along a transect between (A) Androth and Kavaratti. (B) Androth and Kalpeni, (C) Kalpeni and Suheli Par islands and (D) along a north-south transect between 13°45′ and 8°30′N

27.2, maintain almost the same depth both towards east and west, but deepen at the centre of the figure. The σ_t values from 22.5 to 26.5 in Fig. 2D are almost similar to those in Fig. 2B. They slope down northwards.

There is a general upsloping (upwelling) of the water mass towards the west between Kavaratti and Androth and between Androth and Suheli Par islands (Fig. 2A and C). Wind directions at these stations are N to NNW. Displacement of water as a result of such winds will be in the direction WNW to NW. The upsloping of the isopycnals is, therefore, the effect of the prevailing wind system. The downward slopes of the isopycnals indicate a compensatory sinking of the water mass below the vertical displacement. A similar upsloping of the isopycnals at depths above 100 m on the left slope of Bermuda island, looking downstream, has been observed; the explanation given from model studies is that it is due to vertical turbulent mixing which results from the labile nature of the water mass[10].

At or near the island arcs the water moves clockwise around the land mass resulting in a general upward transfer of the deeper water[11]. As has been verified experimentally, such a closed circulation around the islands is due to tangential wind stress and Coriolis force[12].

Rao and Jayaraman[13] observed an upsloping of isopycnals which was limited to the upper 150 m near a station south of Minicoy island along an eastwest transect. This depth agrees well with the present observations. However, similar features could not be observed at a station NE of Minicoy, worked during the 31st cruise, presumably due to seasonal variations in wind-induced upwelling.

It has been shown earlier that because of a stable eddy system present downstream close to Barbados island, the littoral animals with long pelagic larval stages become more abundant than in the exposed areas[14]. Similar eddies seem to be present downstream near the Laccadive islands. The abundance of decapod larvae, including the red prawns, observed in this area in plankton hauls during both the cruises is probably a result of such eddies. Existence of anticyclonic eddies around the islands of Laccadives in the upper 100 m, probably supporting a high productivity in these waters, is also suggested by Jayaraman *et al.*[2].

The northsouth sloping of the isopycnals agrees with the general idea of transport of water masses in the Arabian Sea. The waters coming out from the Persian Gulf (Arabian Gulf) and the Red Sea seek their own density levels as they move towards the equator. Between 13°45′ and 8°30′N, σ_t values of 26.5 and 27.2 slope up by about 100 m (Fig. 2D).

The water masses can also be characterised by the silicate-density relationship such as has been found for waters of the Arabian Sea[15]. The water mass from 0 to 200 m has σ_t values ranging between 22 and 26 and the silicate concentration ranges from 0 to about 35 μg-at/litre (Fig. 3). In the earlier study[15], the range of silicate is from 0 to about 25 μg-at/litre. Higher values, in this study, may be the effect of the upsloping of the isopycnals. The water mass from 201 to 500 m depth has σ_t ranging between 26 and 27 and silicate concentration ranges from 25 to 55 μg-at/litre. The cluster of points at lower silicate values indicates that this water mass is probably from the Arabian Gulf. Similarly, the water between 501 and 1000 m depth with σ_t from 27 to 27.3 and silicate concentration from 45 to 75 μg-at/litre is from the Red Sea. Overlapping of values and points in the figure indicates mixing of different water masses.

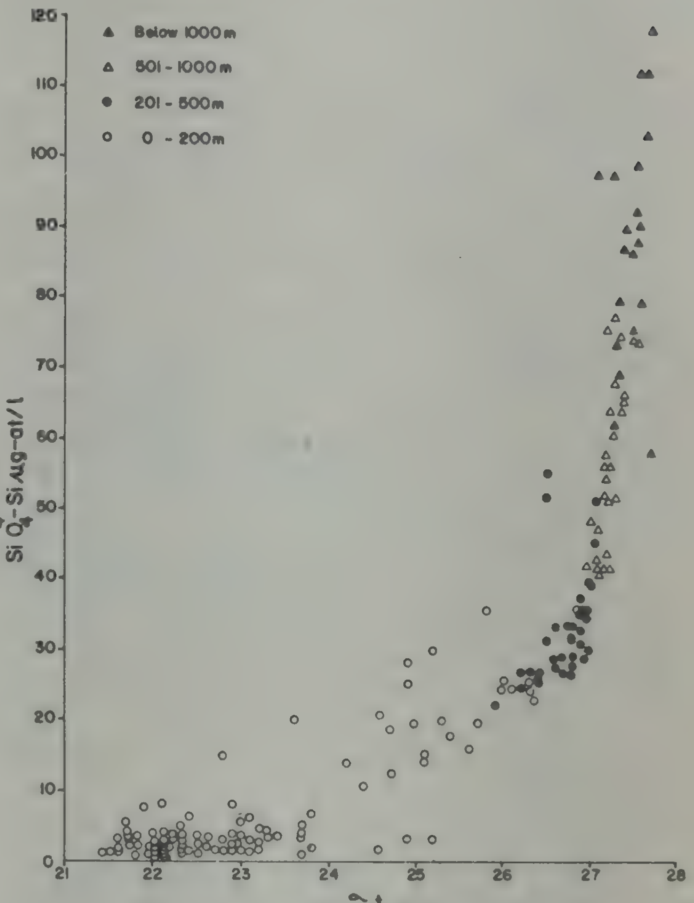

Fig. 3—Silicate—σ_t relationships for different water masses in the Laccadive Sea

Nutrients-oxygen relationships—Two oxygen minima in the water column have been noted at 150 and 800 m depths in the northern and northeastern basins of the Arabian Sea[16]. These basins occur north of lat. 18°N. Vertical distribution of oxygen in the Laccadive Sea has been studied at 3 selected stations (Fig. 4). It is clear from the Figure that 2 oxygen minima start appearing in this area close to lat. 11°N. Curve A in Fig. 4 shows that the upper oxygen minimum layer starts at about 200 m. This is associated with a sharp increase in PO_4^{3-}-P, NO_3^--N and SiO_3-Si and a decrease in *p*H. Maximum value of oxygen is observed at 500 m which is associated with a decrease in silicate and nitrate and an increase in *p*H. This is the effect of mixing of Arabian Gulf and Red Sea waters (Fig. 2D) both of which have low nutrient concentrations, compared to the corresponding depths of the Arabian Sea[17]. The second oxygen minimum appears around 800 m and is the result of denitrification[16]. Although NO_3^--N continues to increase with depth, it is far less than the theoretical amount, determined later in this paper.

Similar features have been observed at the station at 9°15.5′N (Fig. 4C). Here, the oxygen maxima at 500 m are lacking. This indicates the completion of mixing of water masses resulting in homogeneity. At all the stations, nitrite is present in a very thin layer close to the first oxygen minimum layer. Its concentration ranges from 0.16 to 0.20 μg-at/litre.

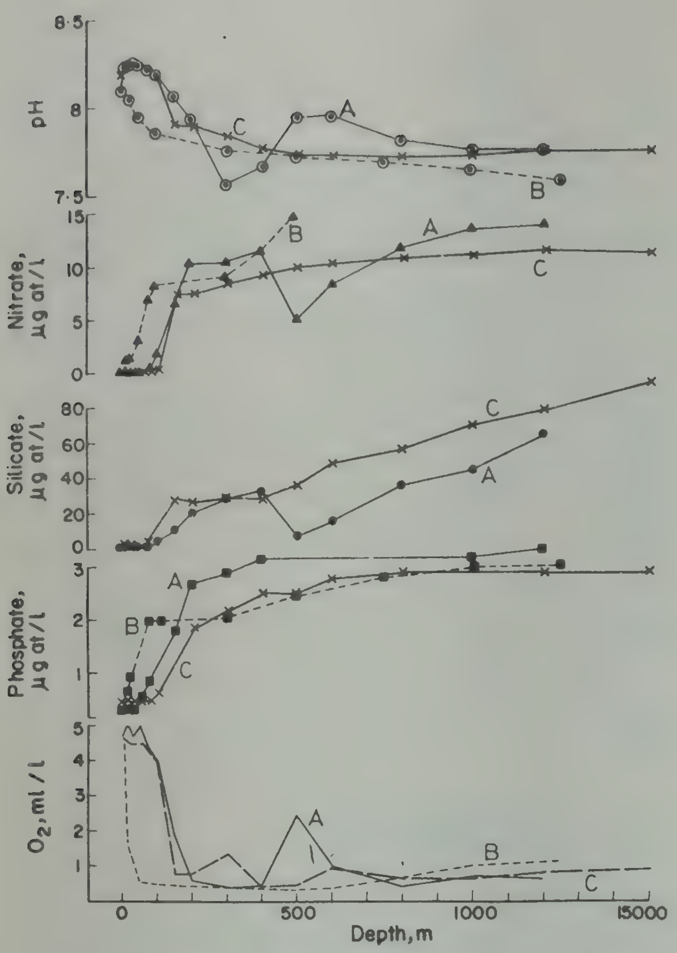

Fig. 4—Depth profiles of chemical components at 3 stations (A) 10°36′N; 72°43′E, (B) 14°00′N; 71°12′E, and (C) 09°15.5′N; 72°35′E

These processes are either absent or not pronounced at the station north of lat. 11°N. This can be seen from curve B (Fig. 4). At this station there is a thick oxygen minimum layer extending from about 100 to about 500 m.

Oxygen, productivity and nutrients—During the 10th cruise, the saturation of water with oxygen between 0 and 50 m ranged from −6 to +10%, while during the 31st cruise the range of oxygen saturation at that depth range was +4 to +12%. During the 10th cruise in October the surface water was fairly warm and undersaturated with respect to oxygen. In the 31st cruise during March-April, which is the transition period from colder to warmer months, the water in 0-50 m zone was normally super-saturated with oxygen.

Photosynthetic productivity ranged from 0.02 to 0.35 gC/m²/day during the 10th cruise[18]. The values during the 31st cruise ranged from 0.08 to 0.83 gC/m²/day[19]. Differences in the productivity values between the cruises are, presumably, due to seasonal variations in the wind-induced upwelling.

Average values for NO_3^--N and PO_4^{3-}-P in the uppermost 100 m depth were 4.21 and 0.97 µg-at/litre respectively during the 10th cruise. In the 31st cruise NO_3^--N decreased to 0.29 µg-at/litre and PO_4^{3-}-P to 0.46 µg-at/litre. During the 31st cruise at almost all the stations NO_3^--N was absent from surface to about 50-75 m depth. Dense patches of the blooms of blue-green alga *Trichodesmium*[20] were associated with NH_4^+-N ranging from 0.5 to 5.5 µg-at/litre at the surface.

Thus, it can be concluded that the constant upward movement of water around the islands becomes an important source for the supply of nutrients in the upper layers of the Laccadive Sea.

The ratios of the change in the concentration of nutrients and dissolved oxygen in water were then calculated as described earlier[15,16]. For this purpose, the values between 150 m and depths of maximum apparent oxygen utilization (AOU) at all stations were used during both the cruises. Oxidative ratios from the depth of the appearance of positive value of AOU up to the depth where it was maximum were determined for all stations. Results obtained are as below:

Ratio	AOU positive to AOU_{max}	150 m to AOU_{max}
ΔAOU:ΔP	263:1	249:1
ΔAOU:ΔN	15:1	19:1
ΔN:ΔP	17:1	13:1

The intercept on the phosphate axis, for the depth range, AOU positive to AOU_{max}, is 1.3 µg-at/litre. This phosphate concentration includes both oxidative and reserved fractions, used in the same sense as used by Sen Gupta *et al.*[16], and indicate that some phosphate is left in the water when nitrate concentration approaches zero. The intercept on the phosphate axis, during the calculation of phosphate-oxygen utilization relationship at 0.66 µg-at/litre indicates only the reserved fraction of phosphate as it is at zero AOU. The balance 0.64 µg-at/litre of phosphate is left at the surface when nitrate concentration approaches zero. This would mean that nitrate would act as a limiting factor for the production of phytoplankton. This accords well with the recent laboratory experiments indicating that below the optimal cell N:P of 30 algal growth is determined solely by nitrogen limitation and above 30 by phosphorus limitation[21].

The amount of phosphate left in the water at zero nitrate value shows a seasonal variation. Calculations from data of 10th cruise in October 1976, give a value of 0.17 µg-at/litre; while the value for the 31st cruise (March-April 1978) is 0.48 µg-at/litre. Similar calculations from the data of *INS Darshak* cruises, in January-May 1974, give 0.1 µg-at/litre[16]; while the values from ISMEX, in monsoon 1973, give 0.29 µg-at/litre[15].

Silicate and oxygen utilization—From silicate concentrations of 0-150 µg-at/litre and AOU values of 25 to 550 µg-at/litre, the following relationship between these 2 variables is deduced[15].

$$AOU = 32 + Si^2/(0.12065 + 0.01025\,Si + 0.00197\,Si^2) \qquad \ldots (1)$$

To test the present values, silicate concentrations are pooled into each 5 μg-at/litre intervals up to a concentration of 10 μg-at/litre and then into each 10 μg-at/litre intervals after calculating the averages for the corresponding AOU values. The values when fitted to eq. 1 the results as shown in Table 1 are obtained.

No zero values of silicate are observed at the surface. Such values are, however, observed during ISMEX 1973 and have been used as $(AOU)_0$ to deduce eq. 1. It appears that silicate values in the surface layers of the Arabian Sea reach about zero only during monsoon. The differences between $(AOU)_{calc}$ and $(AOU)_{obs}$ in silicate concentrations up to 10 μg-at/litre is due to this factor.

The difference in the other ranges lies within the analytical and computational errors. The differences at higher concentrations of silicate agree well with the earlier observations[15]. These are from the samples collected at depths greater than maximum values of AOU. Below this depth oxygen increases steadily resulting in positive deviations (Table 1). It can be concluded that the relation between silicate and oxygen utilization in eq. 1 agrees well with the data obtained from the Laccadive Sea.

Silicate-phosphate relationship—Normally these 2 parameters do not show a linear relation in the ocean. However, in some areas a linear relationship between these 2 has been approximated at selected depth intervals[22,23]. The slope of the regression line between 150 m and AOU maxima for silicate-phosphate relationship, for the present values, gives a ratio of 36:1 by atoms.

Consolidated ratios: Using all the positive values of AOU up to the depths where it is found to be maximum the following atomic ratios are obtained:

$$\Delta AOU:\Delta N:\Delta P = 263:17:1 \qquad \text{... (2)}$$

Table 1—Observed and Calculated Values of AOU at Different Silicate Concentrations

[Values are expressed in μg-at/litre]

Si		AOU		$AOU_{calc}-AOU_{obs}$
Range	Average	Observed	Calculated	
0-5	2.73	104	78	−26
5-10	6.84	91	197	+106
10-20	15	338	345	+7
20-30	25.5	445	423	−22
30-40	34.32	478	454	−24
40-50	43.6	512	473	−39
50-60	54.73	516	487	−29
60-70	65.96	512	496	−16
70-80	75.07	516	502	−14
80-90	84.05	490	506	+16
90-100	95.05	506	510	+4
100-110	104	450	513	+63
110-120	115.23	456	515	+59

Atomic ratios for the same parameters from 150 m to AOU maxima become

$$\Delta AOU:\Delta N:\Delta P = 249:13:1 \qquad \text{... (3)}$$

The ratio between silicate and phosphorus is calculated as

$$\Delta Si:\Delta P = 36:1 \qquad \text{... (4)}$$

Biochemical relationships—Oxidative ratios have been used to deduce composition of plankton in the Arabian Sea[15]. A similar attempt in respect of Laccadive Sea plankton is described here. Assuming what has been suggested by Richards[24] and by applying the relation given in eq. 2, phytoplankton organisms will have the composition $(CH_2)_n(NH_3)_{17}H_3PO_4$.

The overall reaction for oxidation would be

$$(CH_2)_n(NH_3)_{17}H_3PO_4 + (n+34)O_2 =$$

$$nCO_2 + 17\,NH_3 + H_3PO_4 + (n+17)H_2O \qquad \text{... (5)}$$

Since $\Delta AOU:\Delta P$ ratio is 263:1 by atoms, it would give

$$(n+34)O_2 = 263\,O = 131.5\,O_2 \text{ or } n \approx 98 \text{ atoms} \qquad \text{... (6)}$$

The relation in eq. 3 when treated similarly would result in

$$n = 99 \text{ atoms} \qquad \text{... (7)}$$

Thus, for all positive values of AOU from the depth of its appearnace to the depth of its maximum

$$C:N:P = 98:17:1 \qquad \text{... (8)}$$

Similarly, between 150 m depth and the depth of AOU maximum

$$C:N:P = 99:13:1 \qquad \text{... (9)}$$

In the eq. 8, the relation $\Delta AOU:\Delta P = 262:1$ will give

$$\Delta AOU:\Delta C = 263:98 \text{ or } 2.7 \qquad \text{... (10)}$$

In the eq. 9, $\Delta AOU:\Delta P = 249:1$ will give

$$\Delta AOU:\Delta C = 249:99 \text{ or } 2.5 \qquad \text{... (11)}$$

Earlier, Sen Gupta *et al.*[15] obtained

$$\Delta AOU:\Delta C:\Delta N:\Delta P = 280:108:16:1 \text{ or } \Delta AOU:\Delta C = 2.6 \qquad \text{... (12)}$$

The theoretical relation[25] between oxygen consumption and carbon production is 2.6.

The ratio $\Delta Si:\Delta P = 36.1$ by atoms obtained for the Laccadive Sea is not significantly different from 40:1 deduced earlier[15] for the Arabian Sea. Thus, we get

$$\Delta AOU:\Delta C:\Delta Si:\Delta N:\Delta P = 263:98:36:17:1 \text{ by atoms} \qquad \text{... (13)}$$

It can, therefore, be concluded that the atomic relation

$$\Delta AOU:\Delta C:\Delta Si:\Delta N:\Delta P = 280:108:40:16:1 \quad \ldots (14)$$

deduced from the ISMEX and *Meteor* data will be valid for the Laccadive Sea also.

Denitrification—The Arabian Sea and the Bay of Bengal have been observed to be areas where the process of denitrification takes place at an intermediate depth[15,16,26]. The process has been identified to be at the stage of ammonia, without reaching its completion, in the Arabian Sea.

Assuming that the ratio $\Delta NO_3:\Delta PO_4 = 94.5$ occurs during denitrification[24] and that a maximum of 14 μg-at/litre of nitrate can reduced during the process[27], it can be calculated that 14.2 μg-at/litre of nitrate-ion is lost in the waters of the Laccadive Sea. This amount of nitrate would have gone in the accumulation of 2.6 μg-at/litre of ammonia[27]. The average concentration of ammonia between 150 m and AOU maximum in this area has been 1.8 μg-at/litre (ranging 1.4 and 2.4 μg-at/litre). The average concentration of nitrate between 150 m and AOU maximum layer is 17.6 μg-at/litre. This would mean that about 45% of the available nitrate is lost due to denitrification. The data from ISMEX and *Meteor* cruises show a rate of denitrification of 41% for the entire Arabian Sea.

Calcium, magnesium and fluoride—These are generally considered to be major ions in the oceans. Taking into consideration their conservative and semi-conservative properties in seawater, it is thought that their concentrations or their relations with chlorinity may be useful in delineating the characteristics of different water masses.

Measurements of these 3 constituents in the Indian Ocean are few and far between. Calcium and fluoride from the Arabian Sea have been measured earlier[17]. A preliminary analysis of the fluoride values has been presented[28]. Study on these 3 ions at a few stations in the Bay of Bengal and southeastern Arabian Sea has been reported[29]. During the 31st cruise of *RV Gaveshani* 178 samples were analysed on board for fluoride. Sixty samples, collected and preserved on board in sealed polythene bottles, were examined in the shore laboratory for their calcium and magnesium concentrations applying the procedures of Culkin and Cox[30]. In this communication only the general features of these constituents in the waters of the Laccadive Sea are highlighted.

Calcium: Although the average of values in the lagoons (416±0.5 mg/litre for Kavaratti and Minicoy atolls[31]) are somewhat lower than those from the open ocean (425±1 mg/litre), the difference is not very significant being only of the order of ±2% in standard errors.

Measurements made earlier[29] have given an average value of 428 mg/litre for the Gulf of Mannar and SE Arabian Sea and 431 mg/litre for the entire Arabian Sea. The closeness of these values with those from the Laccadive Sea indicates similarities in the chemical nature of calcium all over the Arabian Sea.

Magnesium: The average concentration in the Laccadive Sea is 1339±6 mg/litre while in the lagoons it is 1335 mg/litre[31]. The difference is not significant. Its concentration in the Gulf of Mannar and SE Arabian Sea is 1280±10 mg/litre[29]. The difference may be due to either geographic variation of magnesium in the oceans or spatial changes in its chemical complex formations.

Fluoride: Its concentration in sea water lies more or less well defined at about 1.4 mg/litre at 35‰ salinity.

Fluoride concentration of 1.36±0.01 mg/litre has been observed in the SE Arabian Sea[29]. *Meteor* cruise[17] has indicated an average concentration of 1.19 mg/litre. For Laccadive Sea the average concentration is 1.17±0.01 mg/litre. This appears to be low compared to the SE Arabian Sea and the global mean value. However, it is almost similar to *Meteor* observations. Abnormalities in fluoride values have been reported from time to time. Their causes have been attributed to mainly the localized volcanic activities at the ocean bottom. Fluoride can be removed from the seawater as the sparingly soluble ion-pairs CaF^+ and MgF^+. The formation constants of these ion-pairs decrease with increasing chlorinity[32]. Fluoride can also be removed from seawater as apatite at low *p*H at or near the bottom[33]. It appears that these factors, either individually or collectively, are responsible for these variations of fluoride and magnesium in the Laccadive Sea waters.

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Biological Characteristics of the Laccadive Sea (Lakshadweep)

P M A BHATTATHIRI & V P DEVASSY
National Institute of Oceanography, Dona Paula, Goa 403 004

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Primary productivity, chlorophyll *a*, phaeopigments and particulate organic carbon were studied in the Laccadive Sea during March-April 1978. Column primary productivity, chlorophyll *a* and phaeopigments ranged from 254 to 830 mg C/m^2/day (av. 372), 1.4 to 15.4 mg/m^2 (av. 4.9) and 1.16 to 17.2 mg/m^2 (av. 4.6) respectively. Pigments from nannoplankton were 22 to 100% of the total phytoplankton pigments. Particulate organic carbon values ranged from 1.55 to 6.16 g/m^2 (av. 3.61). *Trichodesmium erythraeum* and *T. thiebautii* were present at all the stations. *Gymnodinium* sp. was mostly present near the islands. Attenuation coefficient varied from 0.061 to 0.113. On an average the detrital carbon was 81% of the particulate organic carbon.

Information on biological characteristics of the Laccadive Sea is confined to areas near some of the islands[1-4]. In order to understand the biological features over larger areas of the Laccadive Sea, a series of cruises have been undertaken on *R V Gaveshani*. The present paper gives some data on carbon assimilation by phytoplankton, chlorophyll (chl) *a*, phaeopigments, particulate organic carbon (POC), nannoplankton pigments, phytoplankton cell counts and attenuation coefficient, obtained during the 31st cruise (March-April 1978). Apart from these, data obtained from the 10th and 13th cruises (October and December 1976) are also presented for comparison[5].

Materials and Methods

Water sampling was done at different stations (Fig. 1) from surface and 4 other depths using a van Dorn sampler. The sampling depths were decided from the attenuation coefficient calculated from Secchi disc measurements such that light levels at the depths were 60, 30, 16 and 1% of the surface. Duplicate water samples (~125 ml) were inoculated with ^{14}C (4 μCi) and incubated by simulated *in situ* technique using neutral density filters to adjust the light levels[6]. Dark bottle samples were immediately filtered and light bottle samples were incubated for 24 hr. Samples were filtered through Sartorius membrane filters (0.45 μm pore size), exposed to acid fumes[6], dried and counted in a scintillation counting system using 15 ml liquid scintillation cocktail (NE 220). Pigment estimations were made by fluorometry after filtering the samples through GF/D pads and extracting in 90% acetone[7]. Contribution of nannoplankton to the total phytoplankton pigment was estimated by passing the samples through 20 μm Nybolt net before filtration for extraction of pigments. POC was measured by the wet acid digestion and spectrophotometry[7].

Results

Primary production, chl *a*, phaeophytin and POC values at surface and column are given in Table 1. Higher rates of production were obtained from the shelf region and lower values from the open sea stations.

Phytoplankton counts ranged from 1900 to 8200 cell/litre in the open sea. Stations situated near the islands (Fig. 1) showed lower counts of phytoplankton

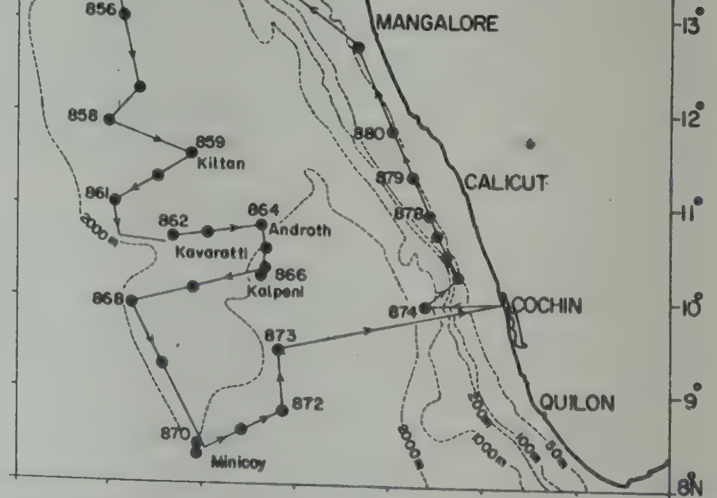

Fig. 1—Station positions (observations were carried out only at the numbered stations)

Table 1—Biological Characteristics of the Lakshadweep Sea during March-April 1978

St No.	Surface						Column						
	*pp mgC/m^3/day	Chl *a* mg/m^3	Phaeo-pigments mg/m^3	Nannoplankton		POC mg/m^3	*pp mgC/m^2/day	Chl *a* mg/m^2	Phaeo-pigments mg/m^2	Nannoplankton		POC g/m^2	Attenuation coeff.
				Chl *a* mg/m^3	Phaeo-pigments mg/m^3					Chl *a* mg/m^2	Phaeo-pigments mg/m^2		
854	2.80	0.13	0.05	—	—	52	829.5	9.05	6.24	—	—	2.81	0.074
856	5.02	0.09	0.06	—	—	20	532.2	15.40	17.22	—	—	5.05	0.085
858	4.00	0.05	0.02	0.01	0.05	44	461.2	7.51	6.36	1.63	3.47	2.46	0.081
859	6.50	0.01	0.01	0.01	0.03	32	330.8	8.05	7.07	5.48	2.95	2.58	0.081
861	4.36	0.02	0.02	—	—	20	264.9	1.61	1.58	1.09	1.77	1.95	—
862	2.37	0.01	0.04	0.01	0.02	41	269.7	2.06	6.71	1.47	3.86	4.15	—
864	2.98	0.10	0.01	0.04	0.01	81	293.5	7.26	4.13	2.74	2.65	4.75	0.074
866	4.40	0	0	—	—	78	456.3	1.43	1.16	—	—	—	—
868	1.44	0.04	0	0.04	0.01	76	423.7	3.88	2.39	3.88	1.02	5.33	0.077
870	3.91	0.15	0.06	—	—	80	270.5	1.65	1.41	—	—	5.36	0.061
872	7.48	—	—	—	—	109	388.2	3.73	1.64	—	—	6.16	—
873	4.89	0.04	0.01	0.02	0.02	98	259.7	2.35	2.34	1.99	2.98	4.50	0.065
874	5.05	0.06	0.05	0.03	0.02	100	257.3	3.27	5.73	1.07	2.66	2.77	0.077
878	30.23	0.08	0.03	0.04	0.14	50	367.0	2.88	2.86	2.44	1.95	1.66	0.094
879	4.62	0.20	0.04	0.08	0.02	62	285.8	5.37	4.01	3.84	1.37	3.03	0.113
880	8.73	0.15	0.04	0.06	0.04	19	253.6	2.23	2.42	2.23	2.95	1.55	0.100
Av.	6.2	0.08	0.03	0.03	0.04	60	371.5	4.86	4.58	2.53	2.51	3.61	0.082
SD	6.7	0.06	0.02	0.02	0.04	30	150.6	3.8	4	1.4	0.88	1.5	

*pp = primary production

(2000-4000 cell/litre). *Trichodesmium erythraeum*, *T. thiebautii* and flagellates were present practically at all stations. The common phytoplankters such as *Navicula*, *Nitzschia*, *Chaetoceros*, *Rhizosolenia*, *Leptocylindrus* and flagellates were mainly present at the coastal stations. Dinoflagellates (*Peridinium* and *Prorocentrum*) were less represented than diatoms at majority of stations. *Gymnodinium* was mostly present at stations near the islands. Zooplankton biomass varied from 2 to 33 ml/100 m^3.

Discussion

Although there are wide fluctuations in the values of different parameters from station to station during March-April 1978, October and December 1976 (Tables 1 and 2) the average values for the 3 periods will provide information on the concentration of the parameters under consideration. The average surface primary production was higher during December as compared to other periods. The higher SD value for primary production during December was because of comparatively higher surface production at sts 220, 222 and 228 (Table 2). The pigment concentration was also high at these 3 stations (Table 2). The difference in the average values of surface production during March-April and October was highly insignificant ($P>0.7$) while those during March-April and Dec. and Oct. and December were significant at $P=0.4$ only. The column production during March-April was higher than that during October and December. The high SD value during December was again due to higher production at sts 220, 222 and 228. However, the difference in the column production of March-April and October was highly significant ($P<0.001$) while that between March-April and December was highly insignificant ($P>0.8$). The difference of the values in October and December was significant ($P=0.025$).

The difference in chl *a* between March-April and October was not significant (av. values are equal) while those between March-April and Dec. and Oct. and December were significant ($P=0.05$ and $P=0.025$ respectively). The higher SD value during December was due to appreciably higher values of chl *a* at some stations (Table 2). The difference in the concentration of chl *a* in the column during March-April and October and October and December was significant ($P=0.2$ and $P=0.025$ respectively). During March-April and December the difference in the column pigment concentration was highly significant ($P<0.001$).

The differences in the concentration of POC of the surface between March-April and October, March-April and December and October and December were significant ($P=0.05$, 0.01 and 0.05 respectively). The column POC values were found to vary much. The differences in the values during March-April and October and October and December were highly significant ($P<0.001$) while the difference between March-April and December was significant ($P=0.01$).

Table 2—Biological Characteristics of the Lakshadweep Sea during October and December 1976

St No.	Surface				Column			
	*pp mgC/m³/day	Chl *a* mg/m³	Phaeopigments mg/m³	POC mg/m³	*pp mgC/m²/day	Chl *a* mg/m²	Phaeopigments mg/m²	POC g/m²
				October				
129	13.29	0.08	0.04	205	358.8	12.00	10.89	33.21
134	14.67	0.12	0.05	709	190.3	8.86	4.24	35.80
137	6.01	0.12	0.05	142	175.9	4.41	8.45	17.30
138A	2.48	0.07	0.05	173	23.0	0.89	0.26	2.04
139	14.03	—	—	142	202.1	—	—	13.50
140	7.91	0.07	0.03	205	92.0	6.61	1.54	18.32
141	5.85	0.13	0.05	79	95.9	7.20	3.79	11.18
143	2.72	0.16	0.05	551	135.3	8.67	3.93	21.91
147	3.54	0.10	0.03	—	177.9	4.09	1.86	—
150	0.53	0.08	0.05	142	21.8	5.39	1.15	13.68
151	0.79	0.02	0.03	173	53.2	3.85	2.70	24.26
153	0.33	0.05	0.03	79	29.5	6.54	6.40	9.39
154	1.94	0.03	0.05	110	98.7	7.23	7.74	19.63
157	1.93	0.05	0.04	173	222.5	7.85	7.22	17.20
Av.	5.43	0.08	0.04	222	134	6.44	4.63	18.26
SD	5.14	0.04	0.01	188	94.7	2.8	3.25	9.2
				December				
212	1.65	0.04	0.03	213	85.0	4.40	3.04	14.30
214	2.96	0.09	0.03	100	110.9	3.84	5.29	6.16
215	3.61	0.15	0.03	246	164.4	16.72	6.75	8.23
217	3.23	0.10	0.01	75	190.2	12.90	6.37	2.00
219A	8.17	0.22	0.04	125	635.6	11.91	4.83	14.75
220	32.89	0.58	0.20	94	578.7	18.86	7.45	11.68
222	28.32	0.17	0.06	150	676.1	16.89	11.49	10.75
225	2.30	0.10	0.03	63	199.9	7.75	15.98	3.62
227	2.96	0.15	0.04	175	115.5	3.98	1.35	8.82
228	42.23	0.33	0.09	50	1166.6	16.55	7.48	3.25
230	3.84	0.10	0.32	50	170.7	9.38	11.35	10.07
233	0.67	0.08	0.06	88	263.9	3.87	7.76	2.63
235	3.55	0.10	0.05	75	44.6	7.08	4.38	1.97
236	4.65	0.11	0.06	50	608.8	7.19	9.49	2.50
Av.	10.07	0.17	0.08	111	357.9	10.60	7.36	7.20
SD	13.62	0.14	0.08	63	324.7	5.0	3.80	4.6

*pp = primary production

Comparison of productivity, chl *a* and POC values indicated how widely they fluctuated during the 3 periods of study. However, the production was maximum during March-April. It was much less than that of Northern Arabian Sea (698 mgC/m²/day) during December 1973 to May 1974[8]. But it was higher than the values of Northeastern Arabian Sea (216 mgC/m²/day) during November 1976[9]. The surface chl *a* value was less than half of that of the Northeastern Arabian Sea[9]. The column chl *a* value was low except in December when it was almost equal to that of Northeastern Arabian Sea. The surface and column POC values during March-April were also less than those of the Northeastern Arabian Sea.

An attempt has also been made to determine the contribution of detrital carbon to POC. Table 3 gives the ranges in POC, phytoplankton carbon, zooplankton carbon and detrital carbon during the 3 periods. Only those stations from where all the 3 parameters are obtained have been included for the analysis. Information on the carbon content of microzooplankton is not available and hence it is not included along with the zooplankton carbon. The conversion factors used in the computation have been taken from Tranter[10].

The contribution of detrital carbon was lowest during March-April and highest during October (Table 3). The average percentage of detrital carbon to POC was 81, 96 and 87 during March-April, October

Table 3—Ranges in POC, Phytoplankton Carbon, Zooplankton Carbon and Detrital Carbon in the Lakshadweep Sea during Different Months

[Values are expressed in mg/m². Average values are given in parentheses]

	POC	Phytoplankton carbon	Zooplankton carbon	Detrital carbon
March/April 1978	1546 to 6155 (3603)	83 to 770 (303)	75 to 672 (368)	984 to 5704 (2932)
October 1976	2045 to 33200 (17425)	45 to 605 (308)	104 to 871 (365)	1900 to 32400 (16752)
December 1976	1969 to 14754 (7194)	192 to 943 (530)	60 to 2040 (376)	1145 to 13945 (6288)

and December. The higher values obtained in October could probably be due to the land run off during southwest monsoon. The range in detrital carbon was least during March-April and highest during October. The detrital carbon was 1 to 56 (av. 10) times the phytoplankton carbon in March-April. The corresponding values ranged from 18 to 122 (av. 55) and from 2 to 63 (av. 12) during October and December respectively. Evidently, there was a decrease in the ratio of detrital carbon to phytoplankton carbon from October to March-April. A similar computation for the Northeastern Arabian Sea (November 1976) gave high ratio of detrital carbon to phytoplankton carbon.

Parsons[11] recorded the average ratio of detrital carbon to phytoplankton carbon to be 5. Ryther and Menzel[12] pointed out that the ratio will be as high as 10 in the upwelling areas. But in the present case, the ratio was quite high (av. 55) especially during October. While discussing this aspect, the influence of monsoon will have to be considered. Tranter[10] while working along meridian 110° E found the detrital carbon on an annual basis to be 2 to 3 times the phytoplankton carbon. Therefore, compared to many of the values reported earlier, the Laccadive Sea contained more detrital carbon.

Zooplankton when considered as a percentage of phytoplankton carbon showed large variations. During March-April, October and December, these values (%) varied from 52 to 824 (av. 252), 29 to 233 (av. 142) and 18 to 342 (av. 81) respectively. The range in the zooplankton carbon computed for the region along 110° E was 17 to 73% of the phytoplankton carbon[10]. In Sargasso Sea, it was 15% of the phytoplankton carbon[13]. In comparison to Sargasso Sea and region along 110° E meridian, the per cent ratio of zooplankton carbon to phytoplankton carbon was much higher in the Laccadive Sea.

The time required (in days) for the complete turn over (i.e. the time needed to produce its own weight of carbon) of phytoplankton at all the stations ranged from 0.2 to 3 (av. 0.8), 1 to 12 (av. 4) and from 0.6 to 8 days (av.3) during March-April, October and December respectively. Thus, the time required for complete turn over was much shorter in March-April than in October and December and this was partially evident from the highest production in March-April. In the tropical zone along 110° E, the time required for this turn over varied from 3 to 10 days[10].

From the foregoing account, it can be seen that the biological characteristics of the Laccadive Sea are somewhat different in March-April from those of October or December. This difference may be due to the difference in the physical and chemical characteristics observed during the different periods.

In general, during March-April the temperature at the surface decreases from coast to offshore and from south to north[14]. The top 50 m is isothermal. Thermocline is between 80 and 125 m. There are indications of the 'rising' of the subsurface waters. During October, the mixed layer thickness varies between 50 and 60 m in the open sea. In shallow seas, the water column is homogeneous up to almost the bottom. During December, the mixed layer thickness is between 50 and 60 m. The vertical structure of temperature during December is similar to that of October. The water masses present in the Laccadive Sea during March-April, October and December exhibited different physical characteristics. Thus, October is the period when upwelling ceases and is expected to be less fertile. The surface layer especially on the continental shelf (top 100 m) is occupied by Arabian Sea upper subsurface waters[15,16]. The σ_t values in the upper 100m are between 23 and 24. But during November-December the low saline Bay of Bengal water enters the Arabian Sea and spreads in a northwest direction and enters the Laccadive region[17,18]. The σ_t values during December is approximately 22 in the upper 100 m water column. By March the Bay of Bengal water has spread quite extensively into the Arabian Sea (see Wyrtki[18], plates 50, 51 and 52). During this month the surface layer (top 100 m) is found to have σ_t between 22 and 23 in a section along Androth and Kalpeni islands. In another section along Androth and Kavaratti σ_t ranges from 22 to 23.5 in the upper 100 m. The σ_t is between 22.5 and 23.5 along north-south section between 13°45′N and 8°30′N (sts 855 to 871)[19]. The above account gives briefly the physical features of the Laccadive Sea during the 3 months.

The chemical characteristics of the Laccadive waters during March-April, October and December also show some differences[19]. During March-April, nitrate-nitrogen is absent at almost all the stations from surface to 50-75 m depth. The surface concentration of ammonia-nitrogen ranges from 0.5 to 5.5 μg-at/litre.

The higher values are probably due to the enrichment caused by *Trichodesmium* bloom. The average PO_4-P and NO_3-N concentrations during March-April (top 100 m) are less than those found during December. March-April is the period when the oxygen (between 0 and 50 m) is supersaturated (104 to 112%) while during October the saturation ranges from 94 to 110%. The supersaturation of oxygen in the upper 50 m during March-April may be a result of higher primary production.

Laccadive Sea has been earlier described as an oligotrophic environment[2]. But present investigation shows that while certain areas of the region can be termed as oligotrophic during October, such situation is not found during other periods. In short, areas which are oligotrophic at certain times can as well be eutrophic at other times as found in the case of the Laccadive Sea.

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Microbial Characteristics of the Laccadive Sea (Lakshadweep)

SHANTA NAIR
National Institute of Oceanography, Dona Paula, Goa 403 004

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Total viable heterotrophic bacterial population of the Laccadive Sea, studied during the 31st cruise (March-April 1978) of *R V Gaveshani*, was moderate. Bacterial population varied significantly both with depth and station. The population density had 2 maxima, one at the surface and the other at 500 m depth. The flora showed a wide range of biochemical activity. The bacterial biomass of the Laccadive Sea, as estimated from the population data was 19.94×10^{17}, equivalent to 3.998×10^{11} μg wet weight or 159.52×10^{8} μg carbon. The annual cycle of bacterial carbon was 498.25×10^{10} μg carbon.

Micro-organisms play a vital role in the metabolism of aquatic ecosystems by introducing the non-utilizable matter into the metabolic pathway. Microbial population forms an important intermediate trophic link through which the energy of detritus and primary production is introduced into the biological productivity of the reef ecosystem[1]. During the 31st cruise (March-April 1978) of *R V Gaveshani* the role of marine bacteria in the ecology and productivity of the Laccadive Sea has been studied. The marine bacterial populations of the water column and shelf sediments of the Arabian Sea have been determined and their role in the biological productivity of the west coast of India has been discussed[2,3].

Materials and Methods

Water samples were collected from 9 stations (Table 1) using Nansen bottles after initial flushing of the water[4]. Nansen bottle was used in spite of the drawbacks because this was the only sampler available on board for collecting samples from deeper stations. However, utmost care was taken to keep the sampler and sample in sterile condition. The effect of hydrostatic pressure was not taken into consideration as the sampling was restricted to 1000 m depth[5]. However, the effect of hydrostatic pressure on the isolates was not studied. Total viable heterotrophic bacterial population was estimated in ZoBell 2216 E medium by plate culture method as the track line in this cruise was purely marine. The population count is expressed as numbers per ml. Morphologically different colonies were isolated and purified by 3 sequential streaking. The cultures thus obtained were tested for different biochemical activities as described by Rodina[6] and Aaronson[7].

Results and Discussion

Spatial distribution pattern of heterotrophic flora— Density of heteorotrophic flora in ZoBell 2216 E medium at different depths is given in Fig. 1. The population data were statistically treated and the analysis of variance at 95% confidence limit indicated that the populations significantly varied both with depth and station. The critical difference determined at 5% level showed that maximum density of population was at the surface. The viable counts showed 2 maxima, one at the surface and the other at 500 m depth (Fig. 1). None of the samples were sterile as was the case from the other regions of the Arabian Sea[3]. The surface counts varied from 7-42/ml (mean ± SD, 18.25 ± 11.63). At sts 857 and 867, unlike at other stations, the peaks were noted at 200 and 500 m respectively. At all the other stations, the counts were generally low at 200 and 1000 m depths. At 200 m, the population was always less than that at other depths and fluctuated between 1 and 7/ml except at st 857 where the density was 22/ml (mean ± SD, 5.2 ± 6.7). The 500 m depth zone had the 2nd maxima ranging between 1 and 19/ml (mean ± SD,

Table 1—Station Numbers, Date and Position
[Sampling depths, surface, 200, 500 and 1000 m]

St No.	Date (in March 1978)	Position	
		Lat. °N	Long. °E
855*	21	13°46′	72°00′
857[f]	22	12°13.5′	72°22′
858	22	11°52′	72°00′
860[f]	23	11°16′	72°31′
861	24	11°00′	72°06′
862	25	10°36′	72°43′
864	26	10°43′	73°38′
867	27	10°05	72°56′
868	27	09°57′	72°16′

*Sample taken at 75 m instead at surface
[f] Sample at 1000 m not taken

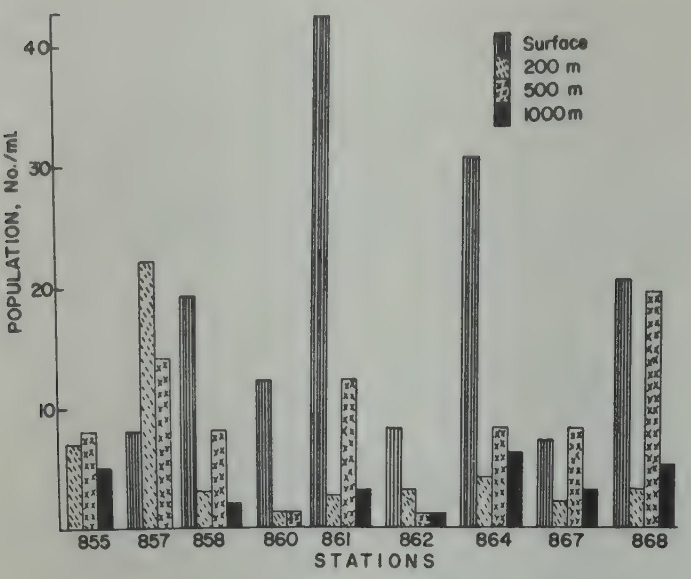

Fig. 1—Total population at different stations

8.7 ± 5.43). The biomass was sparse at 1000 m depth with an average value of 3.7 ± 1.67/ml. Maximum counts of 6/ml was noted at st 864.

At st 855, one sample was collected from 75 m depth instead of the surface. This particular sample showed a very high density (191/ml) which probably reflected the accumulation of particulate matter near the thermocline region[8].

Highest bacterial population was reported earlier at or very close to the surface[3,9]. A similar trend was observed in the present investigation also. High densities in the euphotic zone and a decreasing trend with depth were reported[10-15]. Steele[16] and Menzel[17] suggested that high bacterial biomass in the euphotic zone was due to the recycling of organic matter within this zone. An uneven distribution of the viable counts in the water column[3,18] could be attributed to the availability of easily assimilable organic matter[19,20] susceptible to degradation.

Integrated biomass of water column—To get a clear idea of the standing stock of heterotrophic bacteria in the water column, the population data at different depths of each station were used for calculating the integrated biomass. The integrated biomass thus obtained was further converted to wet weight and carbon value using the conversion factor given by Kriss[4] (Table 2). St 855 showed the maximum value. This higher value was due to the high population of bacteria at 75 m depth. At sts 857, 861 and 868, the biomass varied between 10.25 and $12.8 \times 10^6/m^2$ whereas at other stations the biomass ranged from 2.2 to $8.7 \times 10^6/m^2$. Using the integrated biomass values the total bacterial biomass of the Laccadive Sea was estimated to be 19.94×10^{17}, which is equivalent to 3.998×10^{11} µg wet weight or 159.52×10^8 µgC. The greater significance lies in the quantity of organic carbon cycled annually through bacterial cells. The annual production of bacterial carbon was derived by multiplying the standing crop values by the number of bacterial generations per year. The magnitude of bacterial carbon for the Laccadive Sea, based on the average density was 498.25×10^{10} µg carbon.

Table 2—Integrated Bacterial Biomass

St No.	Biomass/m²		
	No. × 10^6	µg(wet)	µgC × 10^{-3}
855	17.86	3.572	142.88
857	12.8	2.56	102.4
858	6.35	1.27	50.8
860	3.2	0.64	25.6
861	10.25	2.05	82
862	2.2	0.44	17.6
864	8.7	1.74	69.6
867	5.15	1.03	41.2
868	11.6	2.32	92.8

Biochemical activity of heterotrophic bacterial community—Most of the isolates were white or off white in colour. Yellow and orange coloured isolates occurred sporadically (2%). They were gram negative, motile rods except for a few cocci. Most of the isolates displayed considerable biochemical versatality.

It was known that the prevalent potential type of biochemical properties in the heterotrophic bacterial community may provide an important basic information in understanding the mineralisation processes of organic matters[21]. Hence the various biochemical activities of the isolates from the water column were studied.

The productivity of a region would be controlled by the form as well as by the concentration of nitrogeneous compounds present in the water column. Each reaction in the nitrogen cycle would be carried out by micro-organisms possessing that particular biochemical activity. Hence bacterial activities responsible for nitrification, nitrate reduction and urea decomposition were estimated in the present study.

Nitrifiers were encountered only in the surface waters of sts 857, 858 and 862 with activities of 50, 36.8 and 37.5% respectively (Table 3). Spencer[22] and Gunderson *et al.*[23] put forward 2 different explanations for the low activity of the nitrifiers in the surface waters. In the present investigation, nitrifiers were noted only at the surface, unlike in other parts of the Arabian Sea where they were seen in the surface and mid water[3].

Twenty-nine samples reduced nitrate. The analysis of variance at 95% confidence level showed that the population significantly varied with depth and the critical difference ($P \leqslant 0.05$) showed the maximum activity at the surface (Fig. 2a). In 9 samples 100% activity was observed and such a high activity was not restricted to any particular depth. The next highest mean activity was seen at 200 m depth (34.04%). Although the nitrate reducers may be present at any depth where organic matter is rich[23], their activity may be low in surface waters[24] because nitrate reduction at the surface is mainly carried out by phytoplankton. However, it would be of interest to note that nitrate reduction was restricted to the surface waters of the Laccadive Sea and the activity was not parallel to the population density.

Bacteria play a very important role in the breakdown of urea, a major source of nitrogen in the ocean[25]. Urease activity had no particular trend either with depth or with station (Fig. 2b). Only at sts 857 and 868, this activity was present throughout the water column. High mean activity (32.91%) was noted at 500 m depth followed by 17.86% at 1000 m depth. The low activity in the euphotic zone may be due to the assimilation of urea by phytoplankton[25].

The mineralisation of organic matter is mainly carried out by bacteria in planktonic ecosystem[26]. Simple carbohydrates and amino acids are quickly attacked by marine bacteria whereas polysaccarides, lipids and proteins are decomposed slowly. Therefore, proteolytic, cellulolytic, chitinoclastic, amylolytic and lipolytic activities were also determined.

The activity of gelatin and caesin hydrolysers and hydrogen sulphide producers were considered under proteolytic activity. Gelatinase was not evenly distributed. St 868 only had the maximum activity throughout the column. The activity ranged between 12.5 and 91.7% (Fig. 3a). The rest of the stations had a patchy distribution. Casein liquifiers had a wider distribution and were observed almost throughout the water column except at st 862. The peak activity was not confined to any particular depth as 100% activity was noted in one case in the surface and others at or below 500 m depth (Fig. 3b). Generally, the activity was moderate or high in most of the samples. The hydrogen sulphide producers also had an uneven distribution and showed a wide range of activity ranging between

Table 3—Percentage of Biochemical Activities

Activity	Stations							
	857	858	860	861	862	864	867	868
Ammonia oxidation	50	36.8	—	—	37.5	—	—	—
Cellulolytic activity	37.5	15.8	25	4.8	75	3.3	14.3	5
Chitinolytic activity	—	—	8.3	2.4	—	—	—	5

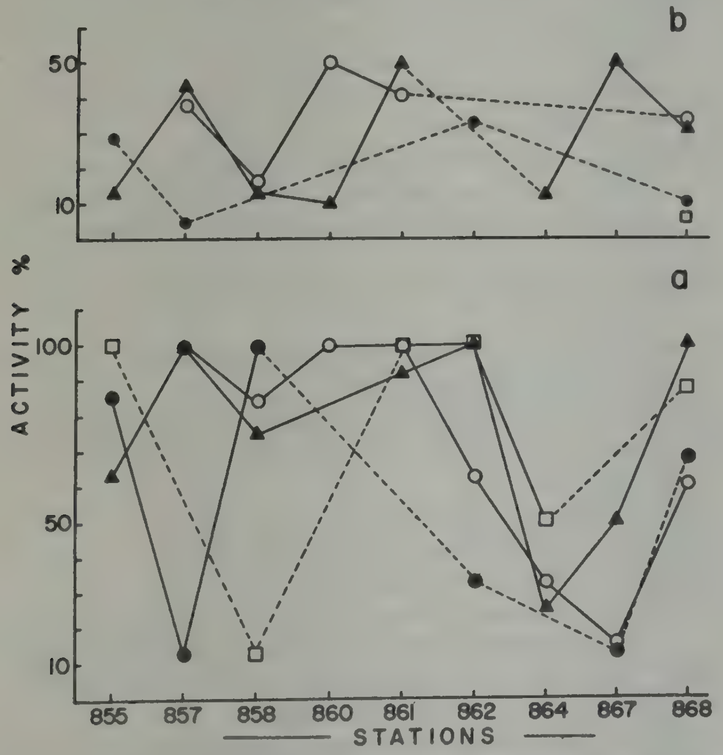

Fig. 2—Percentage activity of (a) nitrate reduction and (b) urea hydrolysation [Activity at depths (m): ○, Surface; ●, 200; ▲, 500; □, 1000]

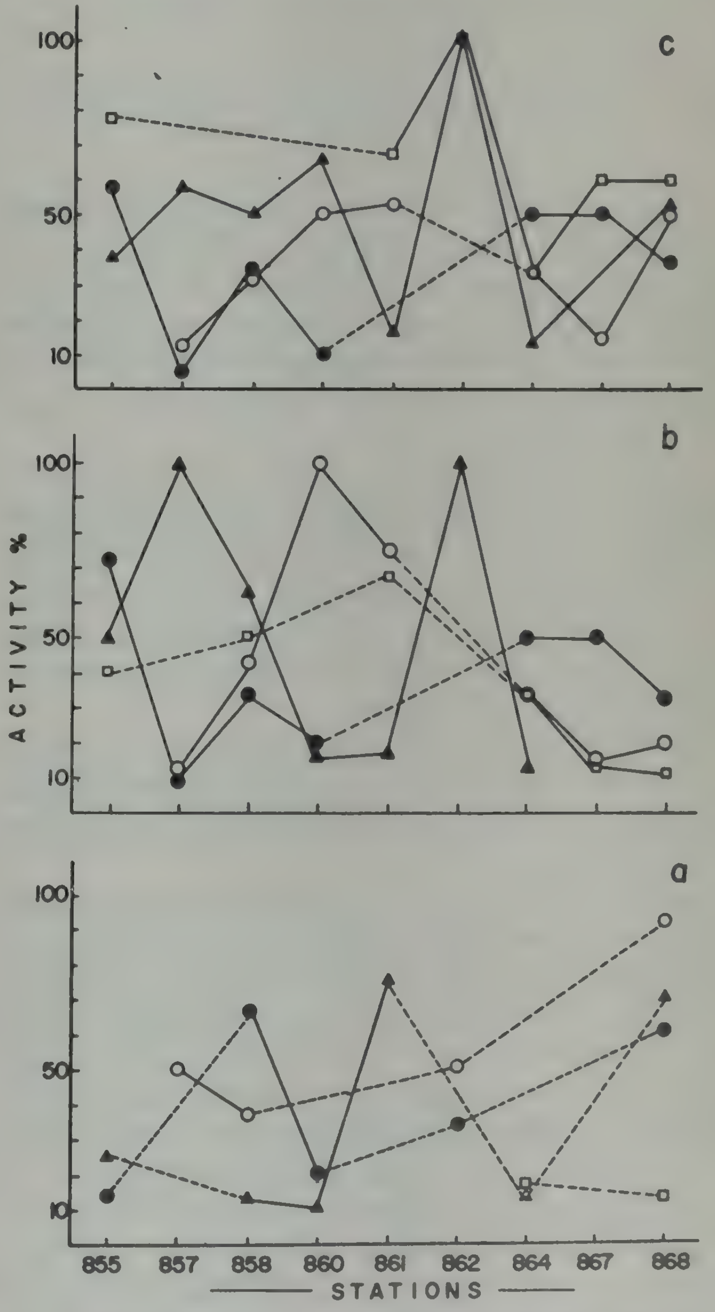

Fig. 3—Percentage activity of (a) gelatin liquifaction, (b) casein hydrolysation and (c) H_2S production [Symbols as in Fig. 2]

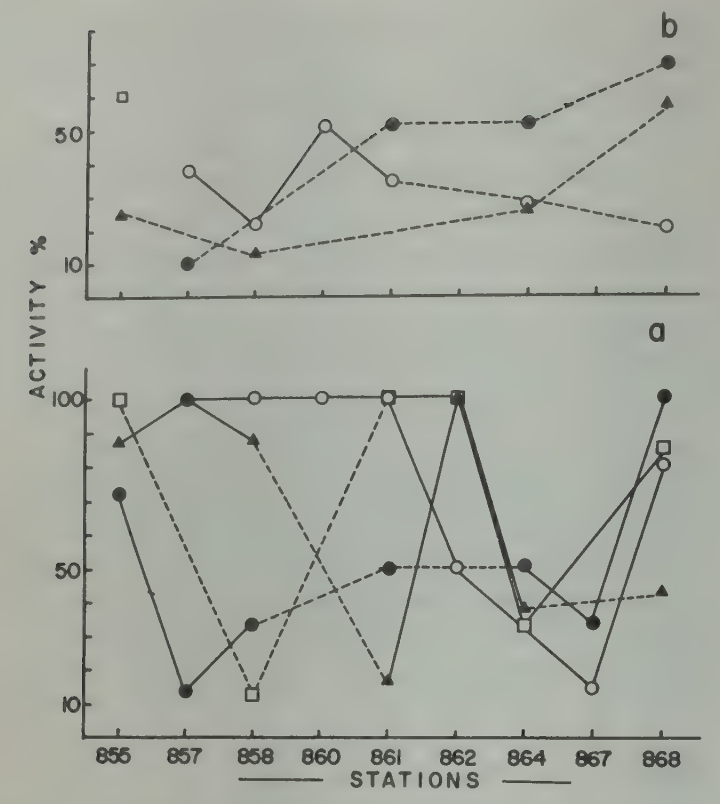

Fig. 4—Percentage activity of (a) starch hydrolysation and (b) fat hydrolysation [Symbols as in Fig. 2]

4.5 and 100%. At 500 and 1000 m depths 100% activity was recorded at st 862 (Fig. 3c). The activity was present throughout the water column at sts 855, 857, 860, 864 and 868. It was noteworthy that proteolytic activity was generally moderate to very high at all stations of the Laccadive Sea, unlike the other regions of the Arabian Sea[3].

Cellulolytic activity was noted only in the surface samples at all stations (Table 3). The activity ranged between 3.3% at st 864 to 75% at st 862. The phytoplankton being a major source of cellulose in the sea, this activity was seen more at the surface waters. However, this activity was reported to be greater in the nearshore bottom deposits[2].

Chitinoclastic activity in the present study indicated that it was only second to cellulolytic activity. Surface samples of sts 860, 861 and 868 showed the activity (Table 3).

Amylolytic activity was invariably noted in samples from all stations and from all depths. The activity was mostly high and 100% activity was seen from different depths (Fig. 4a). Data were statistically analysed and it was found that the activity did neither vary significantly with depth nor with the station. This suggested that the activity of these bacteria was mostly controlled by the availability of carbohydrates.

Lipolytic activity was generally seen at the surface or at intermediate depths and rarely occurred at deeper waters. No activity was seen at sts 862 and 867 (Fig. 4b). The activity varied between 12.5 and 66.6%. It was reported that various physiological groups of bacteria responsible for the degradation of organic matter occur abundantly in association with detritus[27]. Nevertheless, the quantity of detritus settled at the bottom is far more than that suspended in the sea water. This is clearly reflected in the characterisation of the various physiological groups.

Though detailed investigations could be carried out only at 9 stations, the results obtained indicated that heterotrophic community in the Laccadive Sea was moderate and the microbial flora possessed a wide range of potential biochemical activities. The availability of assimilable organic matter[28], to a large extent, determined the capability and versatality of activities of the population. Nontheless, the ecological conditions of the surrounding environment might influence their proliferation and characterisation[29].

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Zooplankton Abundance in the Laccadive Sea (Lakshadweep)

S C GOSWAMI
National Institute of Oceanography, Dona Paula, Goa 403 004

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Zooplankton abundance from the samples collected during the 31st cruise of *R V Gaveshani* (March-April 1978) in the Laccadive Sea (Lakshadweep) was studied. Major planktonic groups showed patchy distribution of abundance in the surveyed region. Copepods were dominant constituents of zooplankton population at all stations. Two harpacticoid copepod species, viz. *Microsetella norvegica* (Boeck) and *Miracia efferata* Dana, were associated with the blue green alga *Trichodesmium erythraeum*. Decapods were better represented in the oceanic region. The gravid females of red bathypelagic prawns, *Acanthepyra sanguinea*, adults and juveniles of *Gennadas* sp. and *Parapenaeus* sp. were recorded in greater numbers around Kalpeni, Androth and Minicoy islands. Zooplankton biomass values at the oceanic stations varied from 4.5 to 37.5 ml/200 m^3. These values were compared with the zooplankton biomass values reported for some regions of the Indian Ocean.

Zooplankton studies from the Indian Ocean received considerable impetus during the International Indian Ocean Expedition (IIOE) when a series of atlases showing the distribution of biomass and abundance of different planktonic groups in the Indian Ocean were prepared from the collected samples[1-6]. Some investigations were carried out on the zooplankton standing stock in the north and northeastern part of the Arabian Sea[7] and in the Bay of Bengal[8].

Studies on the zooplankton population in the Laccadive Sea are rather meagre[9,10] and whatever information is available, is confined to atolls[11-13]. The present paper deals with the zooplankton abundance and distribution of major groups and dominant species in the Laccadive Sea.

Materials and Methods

Zooplankton samples (50) collected during the 31st cruise (March-April 1978) of *R V Gaveshani* were used. Samples were collected mostly from the oceanic region, but a few collections were also made along the continental shelf (Fig. 1). Two series of vertical collections were made, one with the Indian Ocean Standard Net[14], usually from 200 to 0 m and the other with modified HT net[15] from water column above the thermocline layer up to the surface (90 to 0 m). From 6 stations (865 to 870), zooplankton samples were also collected from 500 to 0 m. The depth of the sampling stations along with the date and time of collection are given in Table 1. Zooplankton samples were analysed for determination of biomass and for numerical abundance of major groups and their species wherever possible. Zooplankton biomass was determined by displacement volume method. Depending on the volume of zooplankton sample, a subsample of 4-10% was examined. The number of organisms was calculated for the whole sample and computed per 10 m^3.

Results

Zooplankton biomass—The values during the present study were quite poor for the oceanic stations (av. 14.7 ml/200 m^3). The highest biomass value was obtained at st 863 located near the Kavaratti Atoll.

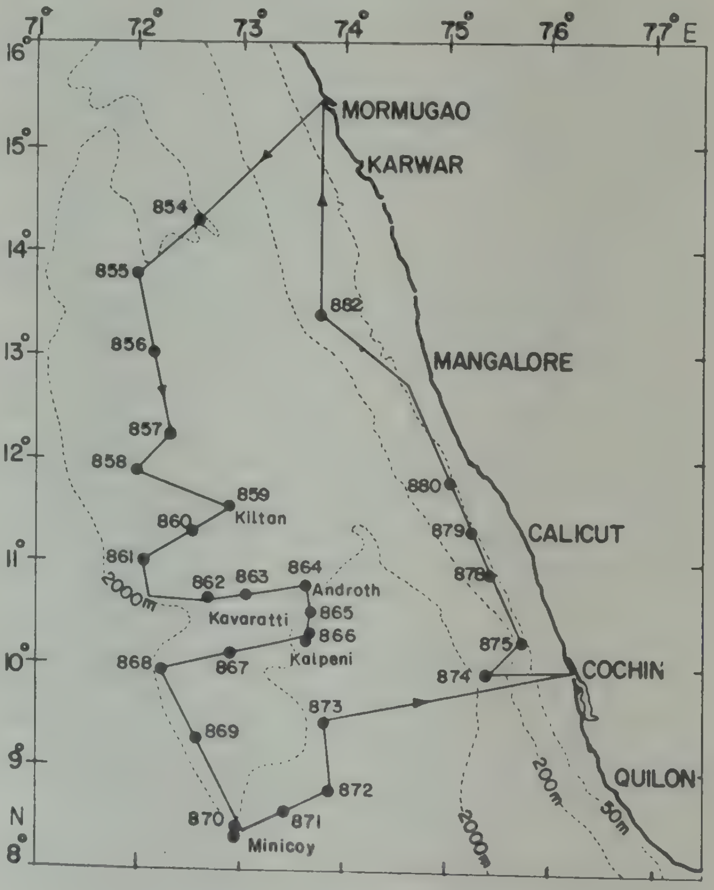


Fig. 1—Location of stations

Zooplankton biomass values were higher for the shelf stations (av. 29.9 ml/200 m^3; Table 1).

Faunistic composition—Copepoda: Copepods (Figs 2A and B) formed a major component of zooplankton community at all stations, constituting 52.7 to 81.4% of total plankton counts. Their population density was slightly higher in the column samples (200-0 m) taken at stations 868, 871 and also at stations located along the continental shelf. The maximum number recorded being 5164.0/10 m^3 at station 875. A total of 106 copepod species were identified from the samples collected above the thermocline layer (Table 2). Most of them (75.47%) were calanoid copepods. The harpacticoid copepods were recorded in small numbers and were represented in the samples by 6 species such as *Longipedia scotti*, *Microsetella norvegica*, *M. rosea*, *Macrosetella gracilis*, *Miracia efferata* and *Clytemnestra scutellata*. Two of these species, viz. *M. norvegica* and *M. efferata*, were invariably associated with the blue green alga *Trichodesmium erythraeum* and were recorded in greater numbers whenever samples contained filaments of blue green alga (Table 3). The cyclopoid copepods were represented by 20 species and majority of them belonged to the family Sapphirinidae.

Spatial variations in the abundance of copepod species were also observed. Species of the genera *Nannocalanus*, *Paracalanus*, *Metacalanus* and *Temora* were recorded more in samples collected from the northern stations whereas species of the genera *Scolecithrix*, *Heterorhabdus*, *Tortanus*, *Sapphirina* and *Copilia* were more abundant from the southern stations. Variations in the occurrence of copepod species in relation to time of collection of samples were also noticed. Members of the genera *Rhincalanus*, *Clausocalanus*, *Centropages*, *Lucicutia*, *Haloptilus*, *Euchirella*, *Pleuromamma*, *Calanopia* and *Acartia* were abundant in the day samples while species of the genera *Nannocalanus*, *Eucalanus*, *Euchaeta*, *Heterorhabdus*, *Sapphirina* and *Copilia* were relatively in greater numbers in the night samples.

Table 1—Details of Collections and Zooplankton Biomass Values of Samples Collected with Indian Ocean Standard Net during March-April 1978

Date of collection	Station No.	Time of collection (hrs)	Depth of sampling stations(m)	Biomass value (ml/200 m^3)
21.3.78	854	1210	2000	11
21.3.78	855	1755	1500	25
22.3.78	856	0300	1400	20
22.3.78	857	1300	1600	13
22.3.78	858	2115	1500	10
23.3.78	859	0700	1000	7.5
23.3.78	860	1400	1800	6
24.3.78	861	0200	1600	14
25.3.78	862	2215	1000	17.5
26.3.78	863	0500	1800	37.5
26.3.78	864	1300	950	11
26.3.78	865	1830	2000	24.5
27.3.78	866	0100	1750	7.8
27.3.78	867	0930	1800	10
27.3.78	868	1800	1400	4.5
28.3.78	869	0300	2000	21.5
29.3.78	870	1645	2000	8.6
30.3.78	871	2230	1900	16
3.4.78	874	2000	1200	14
4.4.78	875	2230	70	32
4.4.78	878	0700	57	11.1
4.4.78	879	1140	50	10
4.4.78	880	1630	52	66.7

Chaetognatha: This group (Figs 3A and B) was well represented in all plankton samples, being second only to copepods in numerical abundance. They were recorded in greater numbers in the samples taken around Androth and Kalpeni islands. Species of the genera *Sagitta*, *Pterosagitta* and *Krohnitta* were encountered in the collections. *Sagitta enflata* and *S. regularis* were the most abundant species in the samples from the shelf.

Decapod larvae: Crab zoeae, megalopa larvae, developmental stages of lucifers, juveniles and adults of prawns of the families Palaemonidae, Pandalidae, Hippolytidae, Hoplophoridae, Pasiphaeidae, Alpheidae, Thalassinidae and Penaeidae constituted decapod population (Figs 4A and B) in the samples. Species of the families Thalassinidae, Hippolytidae and Penaeidae were quite common. The family Penaeidae was represented by *Gennadas* sp. and *Parapenaeus* sp. The gravid females of *Acanthepyra sanguinea* belonging to the family Hoplophoridae were caught in large numbers in the plankton hauls taken from 500 m depth.

Fish larvae: Fish larvae were fairly well represented in all the plankton collections, occurring in greater numbers in the samples taken below the thermocline layer. The highest population density (66/10 m^3) was recorded at station 870, situated near Minicoy island (Figs 5A and B). Fish larvae of the families Holocentridae and Apogonidae were common in the plankton samples.

Discussion

Zooplankton biomass in the Laccadive Sea during the present study showed a patchy distribution. Biomass values during the 10th cruise (6 to 15 October 1976) and 13th cruise (7 to 18 December 1976) were reported[9,10] to increase in the northern and southern areas of the region surveyed. The zooplankton biomass values during the 10th, 13th and 31st cruises to the atolls in the Laccadives varied from 1.9 to 80, 6.2 to 84 and 4.5 to 37.5 ml/200 m^3. During all the 3 cruises, the

Table 2—Population Density of Common Copepod Species of Different Families Collected above Thermocline Layer

[Numbers in parentheses indicate station number]

Species	Maximum population density (No/m³)
Calanidae	
Nannocalanus minor (Claus)	14.1 (859)
Canthocalanus pauper (Giesbrecht)	9.1 (867)
Undinula vulgaris (Dana) var. *typica* Sewell	23.7 (873)
U. darwini (Lubbock) var. *Symmetrica* Sewell	64.1 (855)
Eucalanidae	
Eucalanus crassus Giesbrecht	28.1 (854)
E. subcrassus Giesbrecht	11.2 (882)
E. monachus Giesbrecht	17.6 (867)
E. mucronatus Giesbrecht	31.4 (856)
E. attenuatus (Dana)	15.1 (858)
E. pseudattenuatus Sewell	8.8 (874)
E. elongatus (Dana)	12.5 (864)
E. subtenuis Giesbrecht	4.7 (865)
Rhincalanus cornutus Dana	1.9 (872)
R. nasutus Giesbrecht	6.5 (860)
Pseudocalanidae	
Clausocalanus arcuicornis (Dana)	7.7 (868)
Calocalanus pavo (Dana)	18.3 (855)
Paracalanidae	
Paracalanus parvus (Claus)	44.1 (856)
P. aculeatus Giesbrecht	91.6 (855)
Acrocalanus gibber (Giesbrecht)	17.2 (859)
A. gracilis Giesbrecht	151.8 (854)
A. monachus Giesbrecht	31.2 (869)
A. longicornis Giesbrecht	14.5 (860)
Euchaetidae	
Euchaeta marina (Prestandrea)	36.4 (867)
E. concinna Dana	21.5 (856)
E. wolfendeni A. Scott	9.6 (869)
Euchaeta sp.	11.7 (860)
Aetideidae	
Euaetideus sp.	15.1 (860)
Euchirella bella Giesbrecht	4.6 (867)
Euchirella sp.	16.1 (863)
Scolecithricidae	
Scolecithrix danae (Lubbock)	29.1 (872)
Scolecithrix sp.	13.7 (868)
Centropagidae	
Centropages orsinii Giesbrecht	61.0 (854)
C. alcocki Sewell	13.6 (882)
C. furcatus (Dana)	21.1 (864)
C. trispinosus Sewell	16.4 (865)
C. tenuiremis Thompson & Scott	24.5 (882)
C. dorsispinatus Thompson & Scott	84.9 (874)
C. elongatus Giesbrecht	14.5 (860)
C. gracilis (Dana)	10.1 (862)
Centropages sp.	131.6 (865)
Pseudodiaptomidae	
Pseudodiaptomus serricaudatus (T. Scott)	23.4 (873)
Temoridae	
Temora discaudata Giesbrecht	19.1 (859)
Metridiidae	
Pleuromamma abdominalis (Lubbock)	17.6 (860)
P. xiphias (Giesbrecht)	40.7 (867)
Pleuromamma sp.	2.8 (864)
Lucicutiidae	
Lucicutia flavicornis (Claus)	51.6 (864)
L. ovalis Wolfenden	39.4 (859)
Lucicutia sp.	18.1 (865)
Heterorhabdidae	
Heterorhabdus sp.	61.7 (870)
Augaptilidae	
Haloptilus longicornis (Claus)	18.3 (867)
Haloptilus sp.	18.3 (861)
Arietellidae	
Metacalanus aurivilli Cleve	18.6 (857)
Candaciidae	
Candacia bradyi A. Scott	91.9 (854)
C. pachydactyla (Dana)	21.0 (856)
C. discaudata A. Scott	52.8 (869)
C. aethiopica (Dana)	15.3 (856)
Candacia sp.	77.3 (871)
Pontellidae	
Labidocera acuta (Dana)	29.6 (854)
L. bengalensis Krishnaswamy	121.0 (860)
L. kroyeri (Brady) var. *gallensis* Thompson & Scott	89.3 (862)
L. euchaeta Giesbrecht	34.7 (865)
L. detruncata (Dana)	9.4 (873)
L. acutifrons (Dana)	16.4 (862)
L. laevidentata (Brady)	31.1 (869)
Calanopia elliptica (Dana)	61.7 (866)
C. minor A. Scott	55.1 (857)
C. thompsoni A. Scott	17.1 (859)
Pontella danae Giesbrecht var. *ceylonica* Thompson & Scott	91.0 (860)
P. securifer Brady	20.6 (855)
P. fera Dana	14.2 (855)
P. andersoni Sewell	22.3 (869)
Pontellopsis scotti Sewell	31.5 (865)
P. regalis (Dana)	16.4 (857)
P. herdmani Thompson & Scott	52.6 (873)
Pontellina plumata Dana	33.0 (874)

Contd

Table 2—Population Density of Common Copepod Species of Different Families Collected above Thermocline Layer—*Contd*

Species	Maximum population density (No/m^3)
Acartiidae	
Acartia danae Giesbrecht	114.8 (868)
A. negligens Dana	17.5 (858)
A. erythraea Giesbrecht	89.3 (870)
Tortanidae	
Tortanus gracilis (Brady)	171.6 (874)
T. forcipatus Giesbrecht	50.1 (870)
Longipediidae	
Longipedia scotti (Sars)	0.31 (857)
Ectinosomidae	
Microsetella norvegica (Boeck)	2.18 (871)
M. rosea (Dana)	0.29 (860)
Macrosetellidae	
Macrosetella gracilis (Dana)	0.30 (865)
Miracia efferata Dana	1.13 (872)
Clytemnestridae	
Clytemnestra scutellata Dana	0.21 (867)
Oithonidae	
Oithona plumifera Baird	9.3 (863)
O. nana Giesbrecht	57.8 (859)
O. linearis Giesbrecht	24.9 (855)
O. robusta Giesbrecht	7.2 (855)
O. setigera (Dana)	7.5 (860)
Oncaeidae	
Oncaea conifera Giesbrecht	12.1 (870)
O. venusta Philippi	2.9 (856)
Corycaeidae	
Corycaeus speciosus Dana	4.1 (865)
C. ovalis Claus	8.1 (873)
C. gibbulus Giesbrecht	16.5 (870)
C. catus F. Dahl	13.3 (866)
Sapphirinidae	
Sapphirina nigromaculata Claus	4.2 (871)
S. opalina Dana	1.9 (863)
S. ovatolanceolata Dana	5.5 (863)
S. metallina Dana	19.5 (869)
Sapphirina sp.	4.7 (863)
Copilia vitrea (Haeckel)	3.4 (869)
C. mirabilis Dana	10.2 (874)
C. quadrata Dana	2.8 (863)
Copilia sp.	1.3 (869)

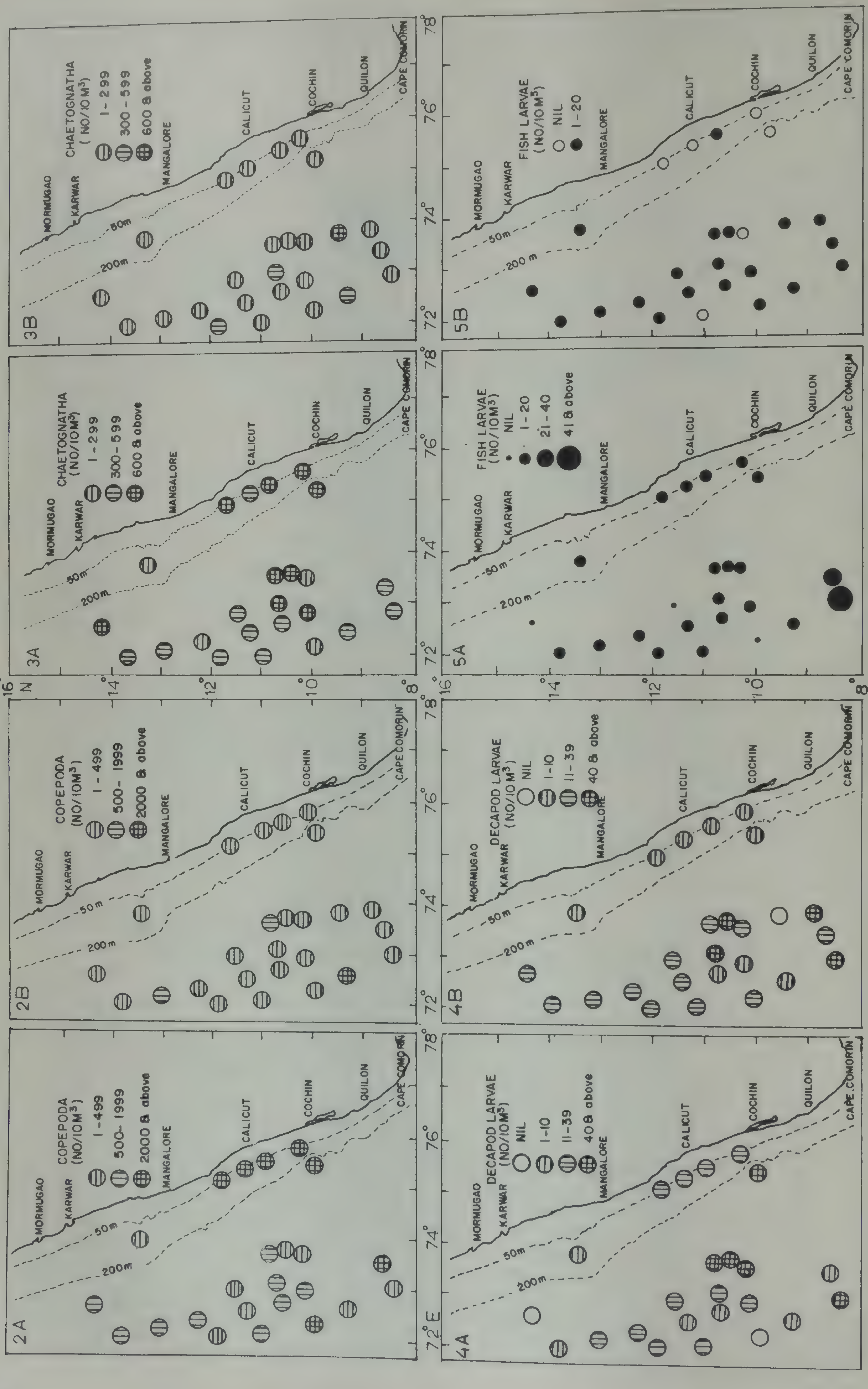
Table 3—Association of Harpacticoid Species (No./100 m^3) with Blue Green Algae

Station No.	Total No. of all harpacticoids	*M. norvegica*	*M. efferata*
854	180	102	64
855	60	34	18
856	50	26	16
857*	70	11	19
858	260	154	61
859	70	38	17
860*	50	10	2
861	130	52	65
862	160	48	93
863	100	27	30
864	220	91	88
865*	60	14	10
866	80	33	40
867*	30	5	1
868	200	109	72
869	180	85	63
870	480	218	113
871	150	55	81
872	170	64	78
873	270	116	130
874	198	102	80
882	32	14	11

*Blue green algae (Trichodesmium spp) not observed in zooplankton samples

worked out stations were located mostly beyond the shelf. The difference in the biomass values may be due to seasonal variation. The first 2 cruises were undertaken during postmonsoon season while the 3rd cruise was during premonsoon months. The zooplankton biomass values recorded from the Laccadive Sea were low as compared to values reported from other regions of the Indian Ocean. During the IIOE collections, the highest value (187 ml/200 m^3) was obtained off Somali coast and based on the same collections, the highest biomass values (>60 ml) for 200 m column was reported for the southeastern coast of Arabian Peninsula[16]. Paulinose and Aravindakshan[7] obtained record zooplankton biomass values (560 ml/200 m^3) in the north and northeastern part of the Arabian Sea.

Distribution of the major planktonic groups, viz. Copepoda, Chaetognatha, decapod larvae and fish larvae,also showed a patchy distribution of abundance. During the present study, population density of the various taxa was observed to be less compared to the values reported earlier[9] for the same area. This depletion in numerical abundance may be due to seasonal difference or due to the occurrence of bloom of blue green algae (*Trichodesmium* spp). Qasim[17] also observed the depletion in zooplankton population


2A
2B
3A
3B
4A
4B
5A
5B
COPEPODA (NO/10M³)
1-499
500-1999
2000 & above
CHAETOGNATHA (NO/10M³)
1-299
300-599
600 & above
DECAPOD LARVAE (NO/10M³)
NIL
1-10
11-39
40 & above
FISH LARVAE (NO/10M³)
NIL
1-20
21-40
41 & above
MORMUGAO
KARWAR
MANGALORE
CALICUT
COCHIN
QUILON
CAPE COMORIN
50m
200m
72°E
74°
76°
78°
16° N
14°
12°
10°
8°

Figs 2 to 5—Distribution of copepods (2), chaetognaths (3), decapod larvae (4), and fish larvae (5) [A, water column (200m-0m); and B, thermocline to surface] during April 1968, when a bloom of *Trichodesmium erythraeum* occurred in the Laccadive Sea. In the bloom areas, copepods formed the dominant constituent of zooplankton community and 2 harpacticoid species, viz. *Microsetella norvegica* and *Miracia efferata*, were found in greater numbers whenever the plankton samples contained filaments of *Trichodesmium erythraeum*. Marumo[18] reported association of copepods and other organisms with the blue green alga, *Oscillatoria* (*Trichodesmium*) *erythraeum*. The decapods, especially the juveniles and adults of prawns were obtained in greater numbers in the plankton samples taken from 500 m to the surface near the atolls. Unusual abundance of gravid females of the red bathypelagic prawns of the family Hoplophoridae was observed around Kalpeni, Androth and Minicoy islands. It appears that these prawns are breeding in this region. The exploratory fishing operations in deeper waters (100-150 fm line) off southwest coast of India have brought to light the existence of large quantities of prawns[19].

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Extracellular Production & Turn-over Rates of Phytoplankton in the Laccadive Sea (Lakshadweep)

A PANT
National Institute of Oceanography, Dona Paula, Goa 403 004

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Extracellular production in the Laccadive Sea is high and ranges between 0 and 78% of total CO_2 assimilation by photosynthesizing phytoplankton. Average extracellular production at the surface is higher than in deeper layers within the euphotic zone which may be a consequence of light intensity. The relationship between chlorophyll *a* and extracellular production is discussed. Data from nearshore regions are compared to extracellular production from the Laccadive Sea. Turn-over rates of phytoplankton biomasses have been calculated from the carbon equivalent weights of phytoplankton and particulate fixation rates. The occurrence of glycollic acid in this area is compared to dissolved carbohydrate values. The possible photosynthetic origin of glycollic acid is briefly discussed.

During photosynthesis phytoplankton release metabolites originating from recent photosynthate[1]. The occurrence of such extracellular products has been reported earlier in tropical waters[2,3]. This paper presents some results of the work carried out during the 31st cruise of the *R V Gaveshani* in the relatively oligotrophic waters of the Laccadive Sea during March-April 1978.

Materials and Methods

Station positions in the Laccadive Sea where measurements were made are given in Fig. 1.

Three depths were sampled within the euphotic zone. In these waters the 1% light transmission level was generally at about 70 m. Therefore, the sampling depths were 0, 15 and 70 m representing respectively 100, 33 and 1% of surface irradiance.

Following the addition of $NaH^{14}CO_3$, from the standard ampoules supplied by BARC, Trombay, samples were incubated under simulated *in situ* conditions for 4 hr. The details of the method used for the analysis of extracellular products were same as earlier[3].

Glycollic acid was estimated using the technique of Shah and Wright[4]. Dissolved oxygen, PO_4-P, NO_3-N, NO_2-N and NH_4-N were analysed simultaneously on board using standard techniques[5]. Chlorophyll (chl) *a* was estimated using a Turner fluorimeter on board and particulate organic carbon samples were stored for subsequent analysis after filtering up to 5 l of water through pre-fired GF/C glass fibre pads.

Results and Discussion

Particulate fixation in these samples ranges from 0.28 to 12.53 mg C/m³/hr at specified depths in the euphotic zone (Table 1). Although individual surface values are slightly higher than those at the 15 m depth (*c* 33% of surface irradiance), these differences are not significant. Qasim[6] and Radhakrishna *et al.*[7] have reported the presence of a sub-surface maximum in particulate fixation in the Arabian Sea and it appears that the depths sampled in the present work lie above and below the depth of maximum particulate fixation. As expected, particulate fixation at the 70 m depth (*c* 1% of surface irradiance) is markedly lower than that of the upper part of the water column, light being the controlling factor.

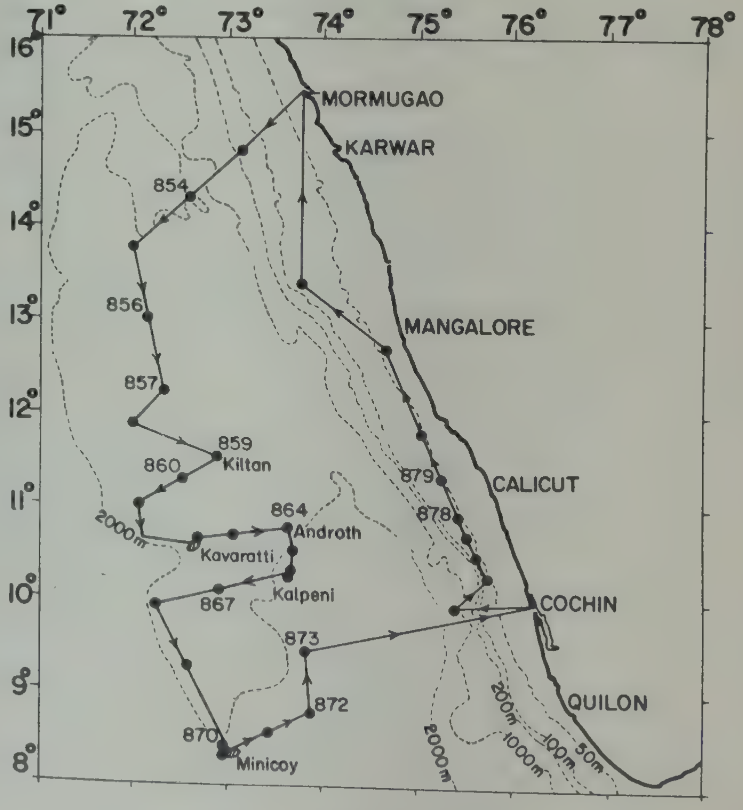

Fig. 1—Station positions

Particulate fixation data (Table 1), when extrapolated to values per day are, on an average 49 ± 19% higher than the data from the same stations and depths where samples were incubated for 24 hr[8]. This difference between the 4 and 24 hr incubations is similar to that reported by Eppley and Sharp[9]. In the present work a value of 50% has been used as an approximation for the calculation of respiratory loss from the live phytoplankton cells. By subtracting the respiratory loss in the dark from the particulate fixation per day it is estimated that the yield at the primary trophic level in the water column of the Laccadive Sea is 375 mg C/m^2/day.

The turn-over rate of phytoplankton, calculated by dividing the carbon equivalent weight of phytoplankton by the rate of addition of fresh organic matter (yield) at the primary trophic level, is 1.1 days in the water column in this area. The carbon equivalent weight of live phytoplankton has been calculated using chl *a* data incorporated in Table 1 and a ratio of 1:50 as chl *a*: phytoplankton organic carbon[10].

The column turn-over rate of 1.1 days is much faster than that reported by Tranter[11] in the southeast Indian Ocean, and may be due to the higher water temperatures in the Laccadive Sea. The turn-over rate at individual depths on the other hand, decreases with increasing depth being 0.4, 0.8 and 2.5 days at 0, 15 and 70 m respectively and is almost certainly related to decreasing light intensity.

Extracellular production in these samples varies from 0 to 3 mg C/m^3/hr (Table 1). The average per cent extracellular production is higher in surface waters (40%) than at 15 and 70 m depths (23 and 10% respectively). The decrease in extracellular production with depth is probably related to decreasing light intensity. Dissolved oxygen concentrations, which can affect extracellular production, are generally 4 to 12% supersaturating up to the 70 m depth in this region[5]

Table 1—Station and Depthwise Estimates of the Given Variables

[Carbon equivalent weights of live phytoplankton have been calculated using a ratio of 1:50 as chl *a*: organic phytoplankton carbon[10]]

St. No.	Depth m	Particulate fixation	Extracellular production mg C/m^3/hr	Extracellular production, % total fixation	Chl *a* mg/m^3	POC mg/m^3	Carbon equivalent wt live phytoplankton mg C/m^3
854	0	0.7	0.4	36	0.12	52	6
	15	1.7	0.3	15	0.12	56	6
	70	0.4	0.22	35	0.18	32	9
856	0	0.7	0.2	22	0.1	20	5
	15	0.7	0.4	36	0.07	44	3.5
	70	0.5	0.1	16	0.56	40	28
857	0	0.35	1.25	78	—	—	—
859	0	1.6	0.4	20	0.006	32	0.3
	15	1.25	0.2	14	0.078	52	0.39
	70	0.28	0.02	6	0.186	15	9.3
860	0	0.9	0.6	40	—	—	—
864	0	0.41	0.47	53	0.1	81	5
	15	1.4	0.6	30	0.1	63	5
	70	0.62	0.2	24	0.13	59	6.5
867	0	0.7	0.6	46	0.01	76	0.5
	15	0.6	0.2	25	0.005	81	0.25
	70	0.55	0.02	3	0.03	81	1.5
870	0	0.27	0.2	42	0.15	80	7.5
	15	0.4	0.4	50	0.01	84	0.5
	70	0.25	0	0	0.01	59	0.5
872	0	1.4	0.4	22	—	109	—
	15	1.2	0	0	0.56	113	28
	70	0.58	0.02	3	0.12	64	6
873	0	0.7	0	0	0.04	92	2
878	0	12.53	3.0	19	0.08	50	4
	10	1.8	0.08	4	0.1	36	5
	50	0.55	0	0	0.1	27	5
879	0	0.4	0.5	55	0.2	62	10
	10	0.34	0.2	37	0.11	81	5.5
	45	0.55	0	0	0.17	31	8.5

and are a likely reason for extracellular production at the bottom of the euphotic zone. There is no significant correlation between the macronutrients such as PO_4-P, NO_3-N with the production of extracellular metabolites.

There is a very highly significant positive correlation ($r=0.93$, $t=12.8$, $P>0.001$) between particulate fixation and extracellular production at all depths. The regression of extracellular production per unit chl *a* on chl *a*, however, is negative and significant ($r=0.4$, $t=2.2$, $2\% < P < 5\%$). These data suggest that wherever chl *a* concentrations are low, release of extracellular matter per unit of chl *a* is high. Similar results have been reported from tropical nearshore waters[3] and temperate freshwater ecosystems[12].

In absolute terms, extracellular production is greater in the nearshore regions[3] with values varying between 0 to 22 mg C/m^3/hr as compared to 0 to 3 mg C/m^3/hr in the Laccadive Sea (Table 1). When both the sets of data are expressed as extracellular production per unit chl *a*, the average extracellular production of 8.37 mg C/chl*a*/hr in oligotrophic waters becomes significantly higher than 2.19 mgC/chl*a*/hr from nearshore environments. This may be due to the effect of self-shading with the higher seston loads in turbid areas as compared to the offshore clearer regions or, as suggested by Fog[13], an effect of mineral deficiency on photosynthesis in oligotrophic waters.

Although the nature of phytoplankton photosynthetic extracellular products in tropical environments remains to be investigated, work in temperate regions has suggested that up to 35.5% of extracellular products of natural phytoplankton populations is glycollic acid[14] which is a product of the photorespiratory pathway in algae[1,15].

Glycollic acid values in the euphotic zone of the Laccadive Sea (Table 2) are generally much lower than those from nearshore values off Goa. As seen from Table 2, offshore values of glycollic acid in the temperate Irish Sea are much lower than those in the tropical Laccadive Sea. If glycollic acid, in fact, constitutes 35.5% of extracellular products, higher temperatures and tropical light intensity are possible causes for the difference in the metabolite concentrations in the two environments.

Furthermore, assuming that 35% of extracellular products is glycollic acid in tropical environments, it is interesting to note that in spite of the higher level of glycollic acid in the nearshore regions (Table 2), the turn-over rate of this compound is approximately 6 days as compared to 15 days in the Laccadive Sea. The faster turn-over rate in the nearshore waters is probably due to higher bacterial biomass and activity. Wright[16] has suggested that extracellular products form an important pathway for the flow of energy from live algae to bacteria at least in freshwater ecosystems and it appears that the same may be true in tropical marine areas also.

Table 2—Glycollic Acid Values from the Laccadive Sea and Other Regions

[All value in mg/m^3 are mean values. SD values are expressed as percentage of mean]

Laccadive Sea				Nearshore values (Off Goa)	Irish Sea
Depth m	Glycollic acid	Dissolved carbohydrates	%		
0	92±50	2800±50	3	542±25	0 to 11
15	89±50	2600±48	3	365± 9	
70	79±50	2500±35	3		

Glycollate forms a very small part of DOM as compared to dissolved carbohydrate in the Laccadive Sea (Table 2, column 4). The large fraction of dissolved carbohydrate probably originates from decaying organisms. When particulate organic carbon data (Table 1) are corrected for the carbon equivalent weight of live phytoplankton it is obvious that the per cent of detritus in the samples is fairly large.

One of the important questions that remains to be answered in tropical environments, apart from the nature of products released during photosynthesis, is the fate of these compounds in these ecosystems. That extracellular products represent a sizeable energy loss to photosynthesizing organisms is apparent from the work presented here and earlier[1-3,12]. Rodhe[17] suggested that phytoplankton organisms may themselves re-utilize metabolites under conditions of light limitation and photoheterotrophic uptake of various organic substrates has been shown to occur by several algae[18]. Thus, dissolved organic compounds of low molecular weight such as glycollic acid may have a very important role both in maintaining phytoplankton viability in adverse conditions and in algae-bacteria energy transfer mechanisms in environments such as the Laccadive Sea.

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Energy Pathways in the Laccadive Sea (Lakshadweep)

S Z QASIM, M V M WAFAR, SUMITRA-VIJAYARAGHAVAN, JOSEPH P ROYAN & L KRISHNA KUMARI
National Institute of Oceanography, Dona Paula, Goa 403 004

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Energy components of the Laccadive Sea include phytoplankton, zooplankton and detritus. Of these, the detritus contributes most of the energy (97%). Large quantities of detritus, many times greater than phytoplankton and zooplankton in the upper 250 m layer, include microbial flakes, organic aggregates, remains of phytoplankton and zooplankton and faecal pellets. Caloric content of suspended detritus is fairly high and similar to that of other water masses. Annual harvestable yield of the Laccadive Sea has been estimated from the total energy contributed by phytoplankton and zooplankton and it is concluded that Laccadive Sea can support fishery many times greater than what is exploited.

It has often been thought that in the open ocean, the basic sources of food or energy are largely phytoplankton and zooplankton. The alternate pathways of energy from detritus and bacteria have seldom been worked out in detail. During the 31st cruise of *R V Gaveshani* to the Laccadive Sea, during March-April 1978, different pathways of energy from living and non-living materials in the sea have been studied.

Materials and Methods

For drawing the energy pathways, 12 stations (Fig. 1) were worked. From each station, water samples were collected using van Dorn samplers. The depth investigated were 0, 60 or 80, 100 and 200 or 250 m. From each depth, total suspended matter, chlorophyll (chl) *a* and detritus were measured by filtering 4 to 9 l of water through GF/C Whatman glass filter pads. The pads were dried to constant weight in an oven at 70°C. The difference in weight before and after the filtration gave the measure of total suspended matter in terms of dry weight. Chl *a* was measured fluorometrically on shipboard. From the chlorophyll content, total phytoplankton component in terms of carbon was determined using the conversion factor 1 mg chlorophyll = 50 mg carbon[1] and in terms of dry weight using the conversion factor 1 mg carbon = 3.3 mg dry weight of phytoplankton[2].

For microscopic analysis, 1 litre of water was fixed with 5% formalin on shipboard and allowed to settle. The settled material was made up to 25 ml. From this, aliquots of 1 ml were pipetted out and examined under a microscope. Zooplankton biomass values available as displacement volume obtained by IOSN[3] during this cruise were converted to wet and dry weights following the conversion factors of Cushing[4] and Cushing *et al.*[2] respectively and finally to carbon using the conversion factor given by Tranter[1]. The quantity of detritus inclusive of bacteria was determined as the difference between the total dry weights of the suspended matter and the dry weights of phyto and zooplankton.

Carbon values of phytoplankton were converted to calories using the conversion factor 1 mg carbon = 11.4

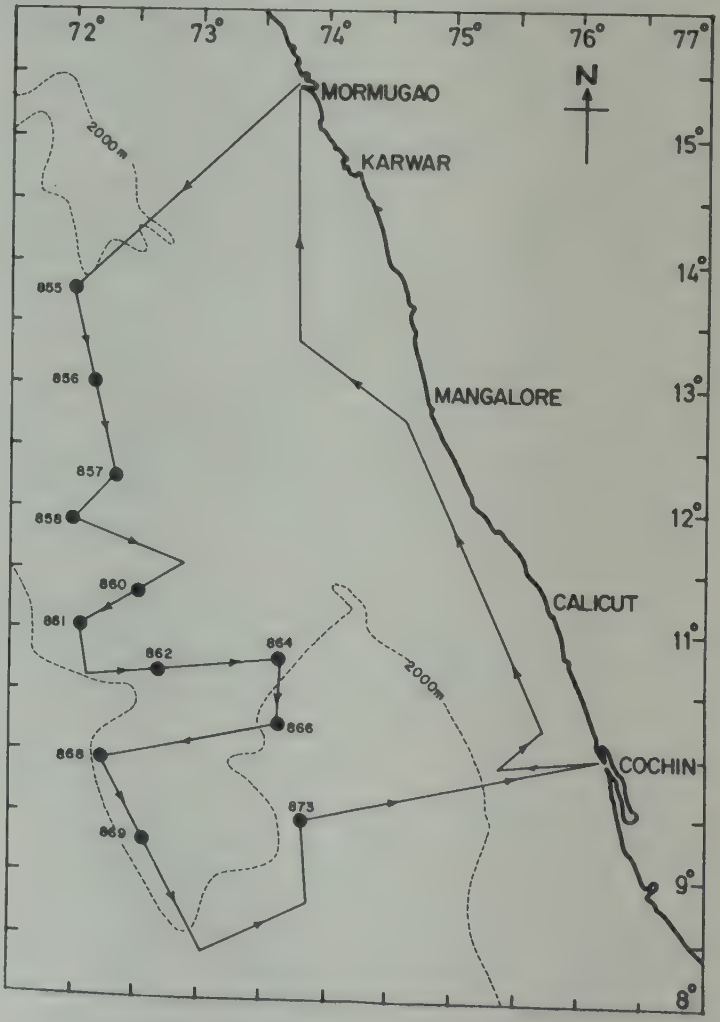


Fig. 1—Stations covered in the present study

calories[5]. Zooplankton calories were derived from carbon values following the factor 1 mg carbon = 10 calories[6]. The total suspended matter after drying was reduced to fine powder. It was then pelleted and combusted in an adiabatic microbomb calorimeter (Parr 1200). Detrital calories were obtained by subtracting the phyto and zooplankton calories from the caloric content of the total suspended matter.

Results and Discussion

Energy components—Microscopic examination of the suspended matter showed that it is composed of phytoplankton cells (diatoms, dinoflagellates, a few blue green algae), intact zooplankton consisting of copepods, nauplii, a few ostracods and colonies of flagellates. The detrital part of the suspended matter included organic aggregates, microbial flakes, decaying algal cells, diatom frustules, appendages of adult copepods and nauplii, moults of crustaceans, faecal pellets and particles of silt constituting the inorganic fraction.

Integrated values of phytoplankton energy along with energy values for zooplankton, suspended matter and detritus for the column of water are given in Table 1. Maximum values were recorded at st 856 and minimum at st 855. The average chlorophyll value in the Laccadive Sea was 4.27 mg/m^2, average carbon value 213.35 mg/m^2 and the phytoplankton energy 2.43 kcal/m^2. The average value for zooplankton dry weight in the Laccadive Sea (0-200 m column) was 3.0 g/m^2 which will be equivalent to 4.50 kcal/m^2.

Total suspended matter in terms of dry weight and energy units varied from 14.96 to 677.43 g dry weight/m^2 or 67 to 501 kcal/m^2 respectively. Detrital energy varied from 64.14 to 493.68 kcal/m^2 with an average value of 226.41 kcal/m^2. On unit weight basis, the detrital energy varied from 0.73 to 4.80 kcal/g dry weight with an average value of 3.85 kcal/g dry weight.

Percentage contribution of energy by living (phyto and zooplankton) and non-living (detritus) components in the total suspended matter is given in Table 2. Of the 3 components, the detrital contribution was the largest (97%) and zooplankton the lowest (1%).

Distribution of phytoplankton, zooplankton and detrital energy in relation to latitudes is shown in Fig. 2. Phytoplankton energy was maximum at lat. 13°

Table 1—Integrated Values of Chlorophyll *a*, Phytoplankton Carbon and Phytoplankton Energy from 0-100 m Column of Water; Zooplankton Weight and Energy from 0-200 m Column of Water and Total Suspended Matter, Detrital Weight and Their Energies from 0-250 m Column of Water at Different Stations of the Laccadive Sea

St No.	Chl. *a* (mg/m^2)	Phytoplankton carbon (mg/m^2)	Phytoplankton energy (kcal/m^2)	Zooplankton dry wt (g/m^2)	Zooplankton energy (kcal/m^2)	Total suspended matter (g dry wt/m^2)	Total energy in suspended matter (kcal/m^2)	Detritus (g dry wt/m^2)	Detrital energy (kcal/m^2)
855 N	1.13	56.5	0.64	5	7.5	79.43	221.44	74.24	213.3
856 D	15.4	770	8.78	4	6	93.43	396.85	86.88	382.07
857 D	3.86	193	2.20	2.6	3.9	64.74	223.73	61.5	217.63
858 D	7.51	375.5	4.28	2	3	677.43	500.96	674.2	493.68
860 D	1.61	80.5	0.92	1.2	1.8	14.96	66.86	13.49	64.14
861 N	2.06	103	1.17	2.8	4.2	108.53	499.01	105.39	493.64
862 N	7.26	363	4.14	3.5	5.25	57.44	227.26	52.75	217.87
864 D	1.43	71.5	0.82	2.2	3.3	23.95	96.22	21.51	92.10
866 N	3.88	194	2.21	3.9	5.85	39.15	111.71	34.61	103.65
868 D	2.31	115.6	1.32	1.5	2.25	27.56	126.9	25.67	123.33
869 N	2.4	120.2	1.37	4.3	6.45	55.79	221.68	50.79	213.86
873 D	2.35	117.5	1.34	—	—	21.55	102.94	21.16	101.60
Av.	4.27	213.35	2.43	3.0	4.5	105.33	232.96	101.85	226.41

N = Night stations; D = Day stations

Table 2—Percentage Contribution of Energy by Different Components in the Laccadive Sea

St No.	Phytoplankton energy	Zooplankton energy	Detrital energy
855	0.29	3.39	96.32
856	2.21	1.51	96.28
857	0.98	1.74	97.28
858	0.85	0.6	98.55
860	1.38	2.69	95.93
861	0.23	0.84	98.93
862	1.82	2.31	95.87
864	0.85	3.43	95.72
866	1.98	5.24	92.78
868	1.04	1.77	97.19
869	0.62	2.91	96.47
873	1.30	—	98.70

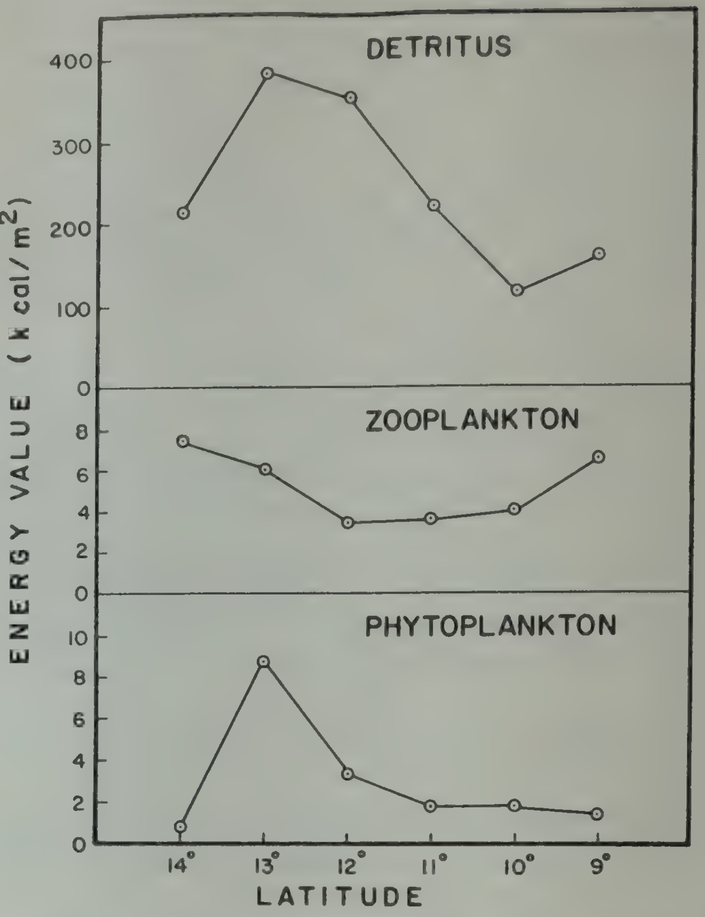


Fig. 2—Caloric values (average) of phytoplankton, zooplankton and detritus in relation to latitudes

and minimum at 14°, while zooplankton energy was highest at lat. 14° and lowest at 12°. Detrital energy was found to be maximum at lat. 13° and minimum at 10° (Fig. 2).

Taking the total area of the Laccadive Sea as 2.3 $\times 10^5$km^2, the phytoplankton, zooplankton and detrital energy was respectively 5.6×10^{11}, 10.35×10^{11} and 520.74×10^{11} kcal.

These figures indicate that phytoplankton and zooplankton constitute only a small fraction of the total particulate matter present in the sea and that the rest of the organic matter appears to exist in the form of detritus.

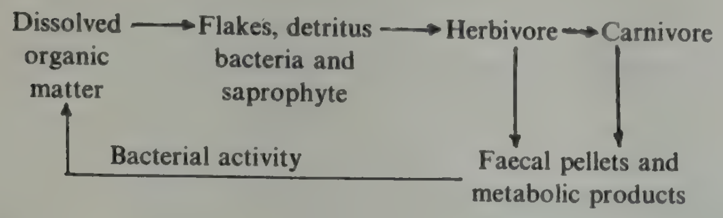
The question which has often been asked is what is the source of such large quantities of detritus in the sea and in what form does it exist? In the estuaries and inshore waters, according to Darnell[7], the sources of detritus could be both autochthonous and allochthonous. However, in the open ocean, no outside source is possible and that almost the entire quantity of detritus must come from within the sea. According to Steele[8], to assume a 'spontaneous creation' of detritus in the sea, many times greater than the living matter, is not possible.

In recent years, our knowledge of the total organic matter in the sea has advanced considerably and there is much evidence available to indicate that enormous reserves of dissolved and particulate matter exist in the sea in the form of 'organic pool'. This pool is far greater than the total stock of living organisms. Unfortunately, our present scheme of production process in the sea is based on the relationship of plants, herbivores and carnivores, which, without taking into account the detritus part, appears to be unrealistic.

Parsons[9] gives the following proportions of organic matter present in the sea: dissolved organic matter 100; particulate matter including microorganisms 10; phytoplankton 2; zooplankton 0.2; fish 0.002. This would mean that the lowest trophic level in the sea starts from heterotrophic bacteria, nannoplankton, ultraplankton and other microorganisms. Thus, the total quantity of organic matter present in the sea would be many times greater than that contributed by phytoplankton[10]. The presence of inert material in suspension increases the colonization of microorganism which, in turn, continues to enhance the total organic matter[11]. Detailed microscopic study conducted on the aggregates and detritus indicates that from the dissolved organic matter, plate-like flakes and flocculant particles (flocs) are continuously formed in the sea which increase the detrital load[12]. Measurements of adenosine triphosphate (ATP) have given some insight into the problem of quantification of bacterial biomass[13], but the total quantity of nonliving material produced in the sea is yet to be determined.

However, besides the continuous regeneration of detritus in the sea, the more important problem is its removal from the system by such mechanism as grazing. Lenz[14] has suggested both direct utilization of detritus by filter feeders and indirect utilization by bacteria and saprophytes and in turn its consumption by filter feeders and herbivores. The second pathway allows recycling of dissolved organic matter and its reentry into the food chain.

In the light of some of the evidences summarized above, the generalized pathway of energy in the Laccadive Sea seems to be:


Dissolved organic matter
Flakes, detritus bacteria and saprophyte
Herbivore
Carnivore
Bacterial activity
Faecal pellets and metabolic products

The average caloric value of detritus from the Laccadive Sea was found to be fairly high. Table 3 gives the energy levels of detritus from different water masses. The average caloric value of suspended detritus from the Laccadive Sea seems to be close to that of the other marine environments. This is largely because the suspended matter from the open ocean contains little inorganic material. However, at stations close to the atolls, fine silt, mainly containing calcium carbonate particles, largely seems to come from coral reefs.

Primary production—Of the 12 stations investigated, only 7 were day stations (Table 1). Chlorophyll values from these stations were used for calculating the rate of primary production. The integrated values of chl *a* up to 100 m depth were converted to carbon assimilation from the method of Ryther and Yentsch[15]. Average solar radiation values were taken from Mani *et al.*[16] and the assimilation number was taken as 6.8 deduced earlier for the coastal waters of the Arabian Sea[17]. The average primary production for the Laccadive Sea was found to be 382.5 mgC/m^2/d or 3.21×10^7 tonnes carbon/yr.

Secondary production—For calculating the secondary production, zooplankton carbon values from the corresponding 7 stations taken for the estimation of primary production, were converted to calories using the conversion factor given by Crisp[6]. Since the copepods were found to be the most abundant organisms in the zooplankton samples, their generation time was worked out using the procedure given by Cushing[18]. Thus, the secondary production was found to be 2.7×10^7 tonnes carbon/yr.

The total energy from primary production for the entire Laccadive Sea would be about 366.29×10^{15} calories and from the secondary production it would be 276.6×10^{15} calories.

Tertiary production—For computing tertiary production, energy values obtained from primary and secondary production rates were converted to live weight according to the factor given by Qasim *et al.*[17]. Then 0.1% of primary production and 1% of secondary production values were taken and the mean of the 2 was determined. This gave the potential fish yield of the Laccadive Sea as 156.62×10^{13} calories or 1659754 tonnes of live weight (see Qasim *et al.*[17]). Since secondary carnivores such as tuna and bill-fishes form the major fisheries which are the long-lived forms, 25% of the potential yield was taken as the harvestable stock. This would amount to 414939 tonnes of fish. According to the catch data collected by the Central Marine Fisheries Research Institute, Cochin for the years 1974 and 1976, the average fish catch for the Laccadive Sea is 2402 tonnes. Thus, a surplus of 4.1×10^5 tonnes of fish seems to be available. The ratio of harvestable yield to exploited yield was found to be 173. This indicates that the present level of fishery exploitation in the Laccadive Sea is rather low and there is sufficient scope to increase the catch.

Table 3—Caloric Values of Detritus from Different Environments Reported by Earlier Authors

[Values represent cal/g dry wt]

Area	Range	Mean
Red Sea[19]	2170-3660	3010
Gulf of Aden[19]	3600-4240	4050
Equatorial Atlantic[19]	3100-4320	3910
Gulf of Mexico[19]	3600-5100	4400
Menai Straits[20] (Suspended detritus)	1076-5542	3263
Cochin Backwaters[21] (Sedimented detritus)	228-500	358
Zuari estuary[22] (Suspended detritus)	173-6057	1463
Laccadive Sea* (Suspended detritus)	732-4804	3850

*Present authors

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Diel Variations of Zooplankton at Kavaratti Atoll (Lakshadweep)

S C GOSWAMI
National Institute of Oceanography, Dona Paula, Goa 403 004

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Occurrence, abundance and diel variations of major groups and species of zooplankton at 2 stations at Kavaratti Atoll (Lakshadweep) during October 1971 were studied. Zooplankton and water samples, for the environmental parameters, were collected at every 2 hr interval covering the entire tidal cycle. Diel variations in the environmental parameters were not significant except for dissolved oxygen content in the lagoon. Average zooplankton biomass values were higher (140.8 g/1000 m^3) for the station outside the coral reef than for the lagoon station (104.7 g/1000 m^3). Nocturnal abundance of zooplankton was observed at both stations. Swarms (31496.0/10 m^3) of the luminescent ostracod, *Cypridina* sp. resulted in high zooplankton abundance particularly in the night samples. Faunistic composition was more diverse at sea than in the lagoon.

Earlier work carried out in the coral reef areas, including the Laccadive archipelago atolls, indicate that zooplankton is an important source of food for coral and coral reef community[1-5]. Production of organic matter from Kavaratti Atoll has been studied[6,7] and the chemical characteristics of the waters around Kavaratti have been described by Sankaranarayanan[8]. The occurrence of a bloom of the blue green alga *Trichodesmium* sp. from the Laccadive region is described by Qasim[9]. The present paper deals with diel variations in the zooplankton community with special reference to copepods at Kavaratti Atoll.

Materials and Methods

Kavaratti (10°33.5′N, 72°38′E) is one of the atolls of Laccadive Archipelago. It is oriented along a north-south axis with the coral reef and lagoon on the west and the island to the east. The average depth of the lagoon is about 2 m.

Zooplankton samples for diurnal studies were taken at every 2 hr interval covering the entire tidal cycle (16-17 October 1971). Horizontal samples were collected from 2 fixed stations (Fig. 1), one situated in the sea and outside the coral reef (st 1) and the other in the lagoon (st 2). Collections from both the stations were made with a square zooplankton net (mouth area 0.25 m^2 and mesh width 0.3 mm). The net was towed for about 5 min and the amount of water filtered was determined by a calibrated flowmeter. Zooplankton samples were fixed in 4% formaldehyde buffered with 1% hexamine. Twenty-six plankton samples were analysed for determination of biomass by wet weight method and for numerical abundance of dominant groups and species. The copepod species diversity values were calculated from the formula given by Fisher *et al.*[10].

Water samples were taken simultaneously with zooplankton collections for the determination[11] of various environmental parameters (*p*H, temperature, salinity, dissolved oxygen content, PO_4-P, NO_3-N and SiO_3-Si).

Results

Diel changes in different environmental parameters are shown in Fig. 2. Changes in *p*H, PO_4-P, NO_3-N values were almost similar at both the stations.

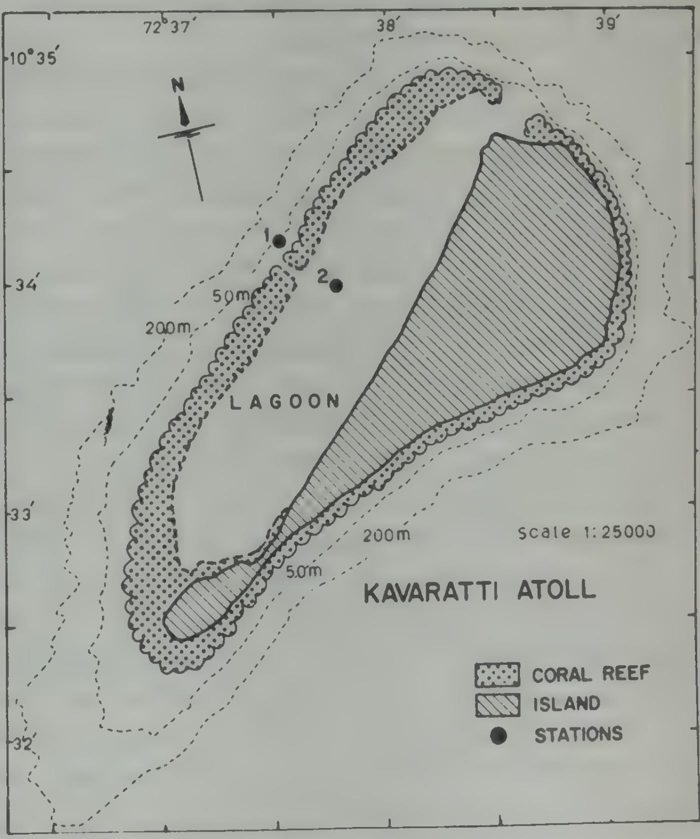

Fig. 1—Location of stations

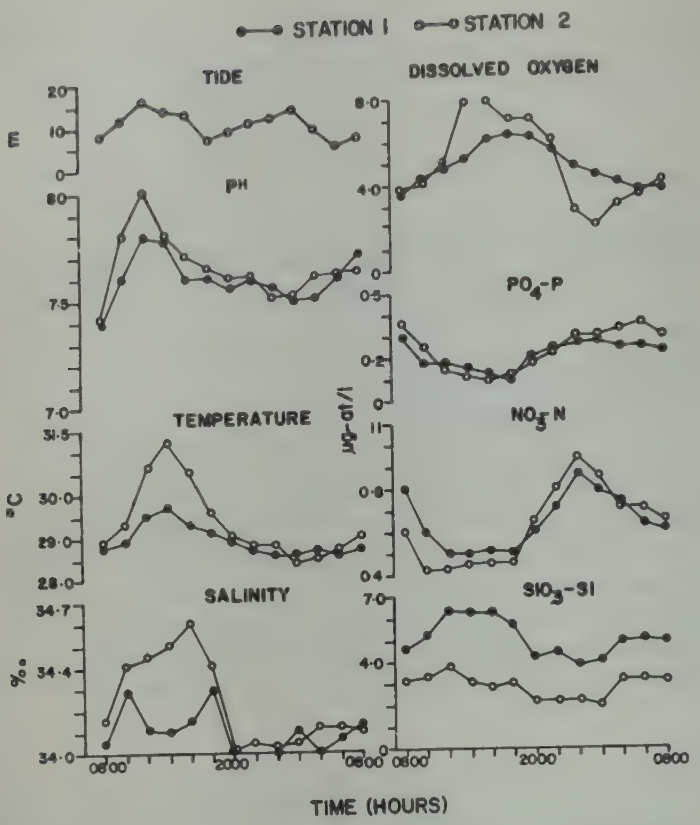

Fig. 2—Diurnal variations in environmental parameters at 2 stations at Kavaratti atoll

Fluctuations in SiO_3-Si values were more at sea. The range in *p*H was from 7.4 to 8 with higher and lower values in the day and night samples respectively. Variations in dissolved oxygen content were particularly significant in the lagoon. Temperature of the water in the lagoon was higher than the surrounding sea and varied from 28.8 to 29.7°C at st 1 and from 28.4 to 31.2°C at st 2.

Zooplankton biomass—Higher values were obtained at st 1 (av. 140.8 g/1000 m^3) than at st 2 (av. 104.7 g/1000 m^3). There was greater nocturnal abundance of zooplankton at both the stations. The biomass values for the night and day samples at sts 1 and 2 were 159.9 and 121.8 g/1000 m^3 and 127.3 and 82.1 g/1000 m^3 respectively. Values were higher for the samples collected during the morning and decreased gradually with the lowest values recorded at 1400 hrs. The values increased again at dusk with peak at 0200 hrs at both the stations (Fig. 3). The tides also influenced the zooplankton abundance and biomass values were higher during the flood tide at st 2 when the oceanic plankton were swept into the lagoon from the surrounding sea. The correlation coefficient (*r*) values obtained between the zooplankton biomass and the various environmental parameters gave negative significant value ($r = 0.711$, $P < 0.01$) with temperature at st 2 indicating a greater zooplankton abundance when the temperature was low.

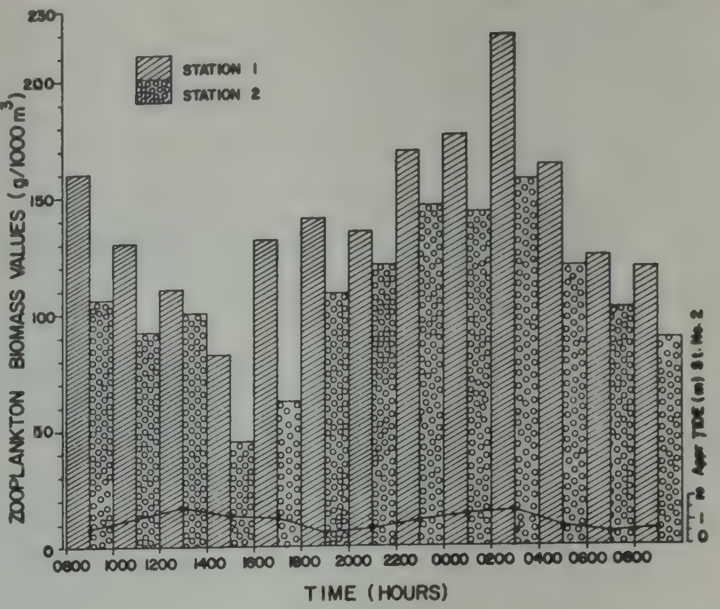

Fig. 3—Zooplankton biomass values at 2 stations at Kavaratti Atoll over entire tidal cycle

Table 1—Percentage Occurrence of Major Planktonic Groups at 2 Stations in Day and Night Collections

Groups	St 1		St 2	
	Day	Night	Day	Night
Hydromedusae	0.8	—	—	—
Siphonophora	0.1	—	—	—
Polychaete larvae	0.31	1.16	1.43	3.27
Cirriped larvae	0.12	—	2.52	0.61
Decapod larvae	3.14	5.09	4.39	3.81
Copepoda	33.74	22.42	5.86	7.36
Amphipoda	—	0.81	3.16	5.83
Ostracoda	55.59	61.39	66.5	70.23
Mysidacea	0.01	2.55	2.99	3.75
Euphausiacea	0.05	0.75	—	—
Chaetognatha	1.14	0.8	0.26	—
Gastropod larvae	1.93	2.03	9.2	3.54
Pteropoda	0.07	—	—	—
Appendicularia	0.15	—	—	—
Invertebrate eggs	2.	1.31	2.05	0.61
Fish eggs	0.44	1.46	0.13	0.92
Fish larvae	0.35	0.19	1.49	0.04

— = Not observed

Species composition and diurnal variation—Ostracods dominated the zooplankton community at both the stations. The faunistic composition showed more diversity at st 1. Hydromedusae, siphonophores, euphausiids, pteropods and appendicularians were recorded only in the samples collected from this station. Diel variations in the occurrence and abundance of major groups were also also observed at both the stations. Based on the total counts of zooplankton, the percentage occurrence of different groups in the day and night samples are given in Table 1. Besides these taxa, few specimens of cyphonautes larvae, isopods, cladocerans, stomatopod larvae were also encountered in the samples and all these constituted minor fraction of plankton population at both the stations. The distribution and abundance of the dominant groups and their species over the tidal cycle at both the stations are as follows:

Copepoda: This group was poorly represented in the plankton samples collected from st 2. However, at st 1, they were recorded in large numbers and comprised mostly of calanoid copepods. The percentage occurrence of calanoid, harpacticoid and cyclopoid copepods at st 1 were 86.73, 2.28 and 10.99% respectively whereas at st 2, their percentages were 27.85, 42.45 and 29.70% respectively.

Qualitative and quantitative variations in the occurrence of copepod species were observed at these 2 stations. Many of the copepod species were observed in plankton samples from st 1 (Table 2). Similarly, harpacticoid forms such as *Clytemnestra scutellata* and *Miracia efferata* were recorded from st 2 (Table 2). Calanoid copepod population was quite poor in the lagoon. *Canthocalanus pauper*, *Paracalanus aculeatus*, *Centropages orsinii* and *Acartia danae* were recorded in greater numbers in the samples collected from the lagoon station during flood tide and were probably brought from the surrounding sea.

Table 2—Population Density (No./m^3) of Common Copepod Species at 2 Stations

Species	St 1		St 2	
	Max.	Min.	Max.	Min.
	Suborder : Calanoida			
Canthocalanus pauper (Giesbrecht)	8.1	0.4	2.3	0.04
Undinula vulgaris (Dana)	36.9	0.5	—	—
Eucalanus crassus (Giesbrecht)	57.2	6.5	3.9	0.3
E. monachus Giesbrecht	2.4	0.02	—	—
E. attenuatus (Dana)	0.8	0.03	—	—
Paracalanus aculeatus Giesbrecht	10.2	0.9	3.4	0.2
Paracalanus spp	113.9	3.2	26.9	0.3
Acrocalanus gracilis Giesbrecht	8.6	0.4	—	—
A. longicornis Giesbrecht	1.3	0.02	—	—
Euchaeta marina (Prestandrea)	0.5	0.01	—	—
Scolecithrix danae (Lubbock)	0.4	0.02	—	—
Centropages orsinii Giesbrecht	14.2	1.3	1.6	0.05
Labidocera pavo Giesbrecht	4.1	0.06	—	—
L. detruncata (Dana)	1.3	0.01	—	—
Pontellina plumata (Dana)	8.6	0.1	—	—
Pontella spinipes Giesbrecht	1.2	0.4	—	—
Acartia danae Giesbrecht	10.2	0.8	8.9	0.01
A. negligens Dana	0.6	0.02	—	—
Acartia sp.	18.7	1.4	3.2	0.5
	Suborder : Harpacticoida			
Clytemnestra scutellata Dana	—	—	6.4	0.02
Macrosetella gracilis (Dana)	2.9	0.4	51.5	0.9
Miracia efferata Dana	—	—	18.6	0.3
	Suborder : Cyclopoida			
Oithona plumifera Baird	1.9	0.2	—	—
O. similis Claus	1.1	0.2	—	—
Oithona spp	18.2	2.1	13.2	0.3
Oncaea venusta Philippi	1.6	0.1	—	—
Corycaeus speciosus Dana	4.5	0.6	—	—
Corycaeus spp	12.3	1.1	2.4	0.7
Sapphirina ovatolanceolata Dana	0.3	0.01	—	—

=Not observed

Species of the genus *Paracalanus* were recorded in large numbers at both the stations. Members of the families Paracalanidae and Centropagidae showed positive correlation indicating that these species can coexist (Tables 3 and 4). The families Macrosetellidae and Sapphirinidae gave negative correlation with most of the other families at st 1 while Macrosetellidae and Clytemnestridae were negatively correlated with other families at st 2 implying that they form a group by themselves and occurred abundantly when the members of the other families were either absent or were poorly represented.

The copepod species diversity (D) values varied from 0.82 to 2.61 at st 1 and from 0.58 to 1.79 at st 2. Higher value at the former station was obtained for the day samples while at the latter station, it was for the night samples. The percentage occurrence of some of the common species over the entire tidal cycle is shown in Fig. 4. These species occurred invariably in all the samples at st 1 but were more abundant in the day collections. However, at st 2, *Clytemnestra scutellata* and *Macrosetella gracilis* were recorded only in the night samples.

Hydromedusae and the siphonophores were obtained in small numbers in the day samples. *Eirene ceylonensis*, *Eirene* spp and *Obelia* spp were the common hydromedusae in the samples and the siphonophores were represented by *Diphyes chamissonis*, *Diphyes* spp and *Lensia* spp. The mysids, viz. *Animysis hanseni* and *Gastrosaccus* sp., were abundant in the samples from both the stations, occurring more in the night samples. *Stylocheiron suhmii* was the only euphausiid species recorded and occurred in greater numbers (112/m^3) at 0200 hrs at st 1. Chaetognath population was quite poor in the lagoon and was not observed there in the night collections. Species of the genus *Sagitta* such as *S. bedoti*, *S. enflata*, *S. neglecta*, *S. pacifica* and *Sagitta* spp were recorded. *S. neglecta* was obtained in greater numbers in the night samples from st 1. *Cypridina* sp. accounted for the ostracod swarms at both the stations. The number as high as 31496/10 m^3 was obtained in the night samples from the lagoon. The decapod population comprised mostly of crab zoea, pagurid larvae, caridean larvae and adults and developmental stages of lucifers. *Lucifer hanseni* was the common species, few specimens of *L. typus* were obtained in the day samples at st 1. The hyperiid

Table 3—Correlation Matrix for 9 Major Copepod Families at St 1 over Entire Tidal Cycle

	Eucalanidae	Paracalanidae	Centropagidae	Pontellidae	Acartiidae	Macrosetellidae	Oithonidae	Corycaeidae	Sapphirinidae
Eucalanidae	—								
Paracalanidae	0.264	—							
Centropagidae	0.318	0.566*	—						
Pontellidae	0.151	0.539	0.698†	—					
Acartiidae	0.373	0.732†	0,589*	0.284	—				
Macrosetellidae	−0.377	−0.529	−0,291	−0.237	0.286	—			
Oithonidae	0.417	0.427	0.411	0.061	0.121	0.325	—		
Corycaeidae	0.354	0.237	0.732†	0.868†	0.326	0.208	0.340	—	
Sapphirinidae	−0.216	−0.279	−0.436	−0.104	−0.174	−0.577*	−0.264	−0.176	—

Significant at *5% and †1% level

Table 4—Correlation Matrix for 9 Copepod families at St 2 over Entire Tidal Cycle

	Calanidae	Eucalanidae	Paracalanidae	Centropagidae	Acartiidae	Macrosetellidae	Clytemnestridae	Oithonidae	Corycaeidae
Calanidae	—								
Eucalanidae	0.162	—							
Paracalanidae	0.774†	0.565*	—						
Centropagidae	0.855‡	0.742†	0.544	—					
Acartiidae	0.929‡	0.262	0.751†	0.836‡	—				
Macrosetellidae	−0.322	−0.422	−0.353	−0.041	−0.262	—			
Clytemnestridae	−0.107	−0.262	−0.217	0.252	−0.110	0.842‡	—		
Oithonidae	0.371	0.514	0.409	0.024	0.416	0.777†	0.724†	—	
Corycaeidae	0.612*	0.609*	0.855‡	0.635*	0.838‡	−0.499	−0.242	0.589*	—

Significant at *5%, †1% and ‡0.1% level

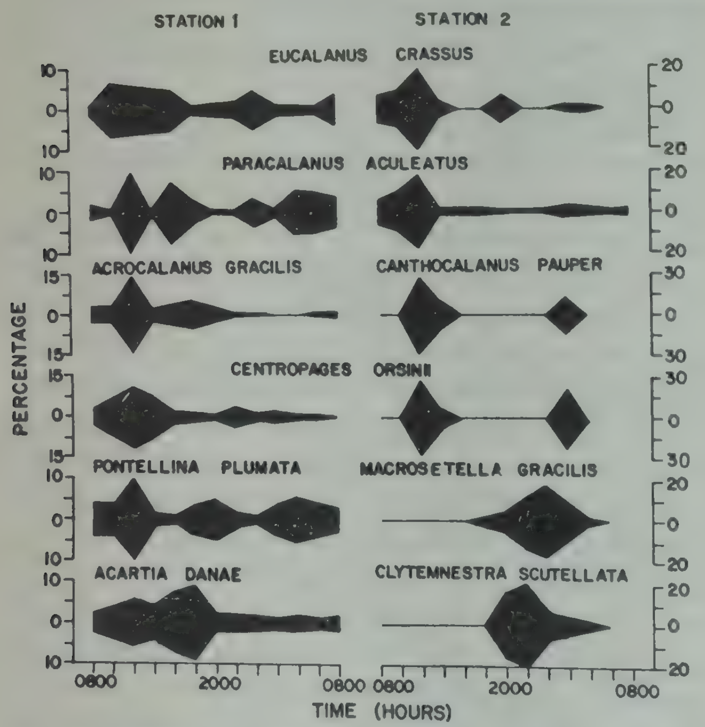

Fig. 4—Percentage distribution of common copepod species at 2 stations at Kavaratti Atoll over the tidal cycle

amphipods occurred in greater numbers at station outside the reef while the gammarid amphipods were abundant in the lagoon. The appendicularians (*Oikopleura* sp.) and pteropods (*Creseis* sp.) were recorded in the day samples. Fish eggs and fish larvae were quite common in all the plankton samples. The fish larvae belonging to the families Gobiidae, Myctophidae and Holocentridae were present in the plankton collections from both the stations.

Discussion

Kavaratti is a perfect atoll[1,2]. It differs from the atolls in the Pacific by the shallowness of its lagoon. The fluctuations in the oxygen levels of the lagoon water may be due to the thick growth of macrophytes and shallow depth. Oxygen values varied from 2.01 to 7.91 ml/litre at the lagoon station. Qasim *et al.*[7] and Sankaranarayanan[8] recorded diurnal variations in the dissolved oxygen content from 3.05 to 7.86 and 1.74 to 8.83 ml/litre respectively from Kavaratti lagoon. The values of nutrient salts were quite low during day but increased slightly in the night samples (Fig. 2). Qasim *et al.*[7] also reported low and high concentration of PO_4-P in the day and night samples respectively. However, for NO_3-N, they observed the reverse trend.

Spectacular ostracod swarms of *Cypridina* sp. contributed to very high zooplankton biomass values at both the stations. Tranter and George[4] also obtained unusually high biomass values from the lagoon (835 mg/m^3) and from the surrounding sea (588 mg/m^3) at Kavaratti Atoll during 20-22 October 1968 and attributed these very high values to ostracod swarms. During the present study, zooplankton biomass values were higher at sea. The mean numerical abundance of zooplankton in the lagoon was about 26% less compared to sea. As the sea water enters the lagoon only on the western side (Fig. 1), it is possible that oceanic plankton are being consumed by the coral reef community from the water flowing across the reef. Tranter and George[4] in their studies of zooplankton at 2 Laccadive atolls reported depletion of zooplankton in transit from ocean to lagoon to be 61 and 23% at Kavaratti and Kalpeni reefs respectively. Glynn[13] gave the rate of consumption of haloplankters at Laurel reef to be 83% at night and 35% during the day.

Diel variations in the occurrence and abundance of zooplankton groups and species were observed at both the stations. Copepod species distribution in particular was quite different in the day and night samples collected from the Kavaratti lagoon. It may not be associated with the phenomenon of vertical migration as the average depth there is about 2 m. The transparency of the water coupled with high incident radiation may be forcing the lagoon plankton to take refuge in the grass bed *Thallasia hemprichii* and *Cymodocea isoetifolia* and come up during the night. Three copepod species, viz. *Clytemnestra scutellata*, *Macrosetella gracilis* and *Acartia* sp., were in association with the grass bed and their gut contents consisted mostly of organic detritus. Fenchel[14] showed that organic detritus derived from the turtle grass serves as food to animal communities. Gerber and Marshall[15] reported that detritus constituted 95% of the gut contents of copepod *Undinula vulgaris* from lagoon of Eniwetik atoll.

Qasim *et al.*[7] obtained high organic production values (4.9 gmC/m^2/day) from the Kavaratti reef which is equivalent to 14.7 mgC/cm/strip/day. This is in order of magnitude greater than the energy available to the reef in the form of zooplankton carbon[4]. From the biomass values recorded from the station outside the coral reef over the tidal cycle, the energy available to the reef in the form of zooplankton carbon works out to be only 0.27 gmC/m^2/day. It means that the energy available to the reef in the form of zooplankton is not sufficient and the coral reef must supplement the food from some other source. Gerber and Marshall[15] stated that mucous and organic particles represent significant source of energy in the coral reef food chain. Existence of demersal plankton in the vicinity of coral reefs was reported[1,3,16] which is supposed to be an important source of energy to the coral reef community.

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Short Communications

Total Mercury Concentrations in Waters of the Laccadive Sea

SUJATA SANZGIRI, R SEN GUPTA & S Y S SINGBAL
National Institute of Oceanography, Dona Paula, Goa 403 004

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Concentrations of mercury, measured at surface and at different depths in the Laccadive Sea, ranged from 50-204 ng/litre, which agreed with the earlier reported values (11-221 ng/litre) for the Arabian Sea. A few isolated values were higher than the average but these were low enough to show that the Laccadive Sea waters are at present free from mercury pollution.

Dissolved mercury in inorganic form occurs mostly as $HgCl_4^{2-}$(ref. 1) and its concentration at the surface of the open ocean is in the range 10 to 100 ng/litre[2-4]. Examining the data available from 1934 to 1972, Fitzgerald and Lyons[5] have reported mercury concentrations in the sea water to range between 3 and 364 ng/litre.

Analysing a few samples from different oceans, including the southern Indian Ocean, Chester *et al.*[6] have reported the mercury concentration at the surface to range from 0.5 to 127 ng/litre. From the iceland waters, the range reported is 12-225 ng/litre[7]. Singbal *et al.*[8] have reported a range of 13 to 187 ng/litre for the total mercury in the Arabian Sea based on observations made during the 16th cruise (March 1977) of *R V Gaveshani.*

The present investigation forms a part of the ongoing project of NIO on the protection of marine environment and monitoring of pollutants in the seas around India and is in continuation of the earlier observations in the Arabian Sea[8].

Sea water samples for mercury analysis were collected from the Laccadive Sea (8°-14° N and 71°30′-74° E) in March 1978 during the 31st cruise of *R V Gaveshani.* The surface samples collected were either from 5 or 10 m depth. This was done to have a comparison of mercury with the other heavy metals and to avoid contamination from the 3.5 m metallic hull of the ship. The sampling stations are presented in Fig. 1. Methods of sample collection, storage and analysis were similar to those reported earlier[8].

Four replicate runs of 20 samples and a mixture of equal aliquots of all the samples established a standard deviation for the values. This when expressed as coefficient of variation, was ±4.5%.

Before acidification, the samples were neither filtered nor centrifuged on board. Therefore, the concentrations reported here include the contribution of acid leachable mercury associated with particulate material also.

Some of the mercury dissolved by the acid treatment may be in an organically bound form and this quantity will appear in the measurements reported. Burton and Leatherland[9] have found that the acid leachable portions were not > 10% of the total measurable mercury in dissolved form. This method will also estimate methyl mercury, if any, in the samples[7]. The presence of organic mercury is yet to be detected in ocean water and there is considerable doubt whether it remains stable in normal oxygenated sea water[10]. The values are, therefore, expressed as total dissolved mercury concentrations in the samples.

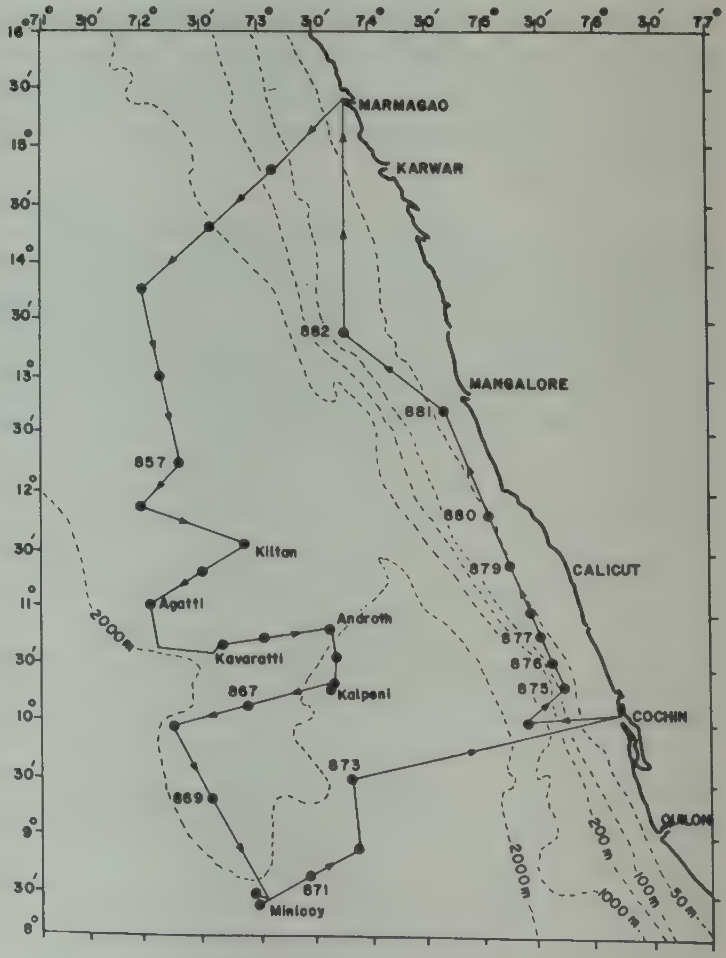

Fig. 1—Station Locations

Table 1—Mercury Concentrations in the Laccadive Sea (Lakshadweep) Part and Indian Coastal Zone of the Arabian Sea from 22 March to 6 April 1978 and Water Masses (Cruise 31)

St No.	Position	Water mass	Sampling depth (m)	Temp. °C	Salinity ‰	Mercury conc. ng/l
857	12°13.5′N	Arabian Sea surface	10	28.31	35.63	60
	72°22′E	do	100	27.69	36.29	50
		Red Sea	500	11.82	35.39	ND
		N. Indian Ocean Deep	1000	8.47	35.24	25
867	19°05′N	Arabian Sea surface	10	29.06	34.90	75
	72°56′E	do	100	27.27	35.89	25
		Red Sea	500	12.83	35.23	ND
		N. Indian Ocean Deep	1000	9.56	35.19	ND
869	09°16.5′N	Arabian Sea surface	10	29.05	34.41	100
	72°35′E	do	100	27.72	35.41	ND
		Red Sea	500	11.77	35.34	50
		N. Indian Ocean Deep	1000	8.54	35.16	50
871	08°32′N	Arabian Sea surface	10	29.49	35.21	100
	73°26.5′E	do	100	26.01	36.03	50
		Red Sea	500	10.83	35.27	ND
		N. Indian Ocean Deep	1000	7.66	35.1	ND
		do	1500	5.27	35.02	25
873	09°26′N	Arabian Sea surface	10	29.9	34.55	120
	73°45′E	do	100	27.19	36.10	50
		Red Sea	500	10.35	35.25	60
		N. Indian Ocean Deep	1000	7.14	35.04	25
		do	1500	4.93	34.90	ND
		do	2000	—	—	25
875	10°14.6′N		10	30.13	34.61	204
	75°44′E		50	28.92	34.91	100
876	10°28′N		10	—	—	180
	75°38.4′E		50	—	—	120
877	10°40′N		10	—	—	175
	75°34′E		50	—	—	100
879	11°20′N		10	29.33	34.99	160
	75°16.2′E		45	29.20	35.12	60
880	11°47′N		10	29.21	35.05	100
	75°04.1′E		45	28.75	35.15	45
881	12°40.2′N		5	29.58	35.35	120
	74°40.8′E		30	28.95	—	100
882	13°24′N		5	29.11	35.36	50
	73°45′E		30	28.93	35.35	50

ND = Non-detectable

The results are presented in Table 1 and results of a few stations away from the Laccadive Sea, are also given for comparison. The area investigated has several water masses. Some attempt has been made to determine whether there is any relation between the concentration of mercury and the different water masses. For this purpose, the water masses from which the samples are drawn have been identified using the classification of Rochford[11] for the Indian Ocean. The data in Table 1 provide very little evidence for any correlation between mercury concentration and a particular water mass. However, it can be seen from the Table that the Red Sea and the North Indian Ocean Deep Water masses contain very little or no mercury.

Analysing a few surface samples, collected between 26° and 28°S in the Indian Ocean, Chester *et al.*[6] have reported values varying from 9-52 ng/litre. This area being somewhat north of the subtropical convergence in the Indian Ocean, lies close to the sources of origin of the north Indian Ocean Deep Water. Values between non-detectable limit and 60 ng/litre are observed in the present study from the area 8° to 12°N at depths having a similar water mass (Table 1). This agreement is interesting and the slight variation obtained between the 2 sets of values may be due to some mixing with overlying and underlying water masses. This is only a conjecture as the values are too few to draw any definite conclusions.

Variations of mercury with depth have been studied at st 873 where sampling has been done up to 2000 m. Concentrations decrease with depth. This is attributable to different characteristics of the water masses as noted above or to the general cycle of mercury in the marine environment.

In the Laccadive Sea, mercury values in general at the surface increase from north to south. A similar trend has been observed in the coastal regions of the Arabian Sea in the same season (premonsoon)[8].

In general, the surface mercury concentrations decrease as we move offshore. This is in agreement with the observations in the Arabian Sea made earlier[8].

A high mercury concentration at the surface was observed during the 16th cruise at st 326. This solitary high value was left out for further confirmation as it was suspected that this might be the effect of some contamination[8]. Mercury deposits were observed in crustal rocks of the hinterland between Calicut and Karwar[12]. This might affect the surface concentration of mercury in this area due to weathering and atmospheric flux. To test this idea further, close sampling was made during the 31st cruise in that area at about 50 m isobath (sts 875-881). Surface concentrations ranged from 100-204 ng/litre (av. 156 ng/litre). The values, excluding one, were not higher than those from the other stations. Hence, the leaching of the mercury from the hinterland did not appear to be very significant. The existence of one isolated high value, however, remains unexplained.

Average surface mercury concentration in the Laccadive Sea was 91 ng/litre (range 60-120 ng/litre). In the coastal waters of the Arabian Sea the average surface value was 136 ng/litre[8] and for the entire Arabian Sea the average value at the surface was 120 ng/litre. Pooling the observations of all the cruises the average concentration at the surface for the northern Indian Ocean would be 106 ng/litre.

There are very few observations on the mercury concentrations from the surface waters of the open ocean. The reported range values (ng/litre) are: Atlantic[6,7], 0.5-225; Pacific[5], 12-153; Southern Indian Ocean, 9-74; China and Japan Seas[6], 6-51; and northern Indian Ocean, 0-221.

Kureishy *et al.*[13] have analysed a few edible fishes from the Indian Ocean and obtained a concentration of 0.09-0.21 ppm (wet weight basis) of mercury. This range is far below the limit of acceptability (0.5 ppm). Combining present observations for the water, with their data, for the edible fishes, it can be concluded that the Indian Ocean is almost free from mercury pollution.

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Trace Metals in the Laccadive Sea

SUJATA SANZGIRI & CAROLINE MORAES
National Institute of Oceanography, Dona Paula, Goa 403 004

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Concentrations of Cu, Fe, Mn, Zn, Co and Ni, measured both in dissolved and particulate forms at 5 stations in the Laccadive Sea, were within the range reported for other areas of the world ocean. Only one station away from the islands, showed somewhat higher values for most of the metals. Dissolved Cu showed a decrease with depth. Dissolved Fe and Mn, on the other hand, showed a marked increase at a depth of 500 m.

The metals Cu, Fe, Mn, Zn, Co, Ni occur in sea water in different forms. These metals can become toxic to marine life when they exceed certain levels of concentration. To predict the trace metals acting as pollutants, it is necessary to have data of their baseline concentrations. Metals in particulate forms occur in the sediments and their presence is closely linked with the chemical and hydrological properties of the sea. The particulate forms also form a part of food of some detritophagus organisms.

Samples were collected with utmost care to avoid contamination in PVC van Dorn samplers with rubber sealed end-caps. The minimum depth was fixed as 10 m so as to avoid contamination due to the 3.5 m ship's metallic hull.

Samples were filtered through 0.45 μm millipore filters under vacuum. The filtrate was transferred to acid-washed polythene carboys and acidified to *p*H 3-4 with 1 *N* HCl. The filter papers having the suspended material were refrigerated in flat plastic containers. The containers with the filtrate and the filters were transferred to the shore laboratory for analysis.

To determine the concentrations of dissolved metals, each sample was divided into 4 aliquots of 400 ml each. Using the method of Brewer *et al.*[1] these were spiked with known concentrations of standard solutions of different metals, chelated with ammonium pyrolidine dithiocarbamate (APDC) and solvent-extracted with methyl isobutyl ketone (MIBK). The concentration of each metal was estimated by atomic absorption spectrophotometry (Hilger Watts Atomspek model H 1550).

Dissolved manganese remained unextracted with APDC-MIBK combination. Hence, it was separately extracted by chelation with sodium diethyl dithiocarbamate at *p*H 5-6 and solvent extraction with MIBK. It was found to give maximum recovery at this *p*H range.

The filter papers with the suspended matter and blank filters were dried in a desiccator containing silica gel and weighed. The filters were then transferred to conical flasks and to each 1 ml perchloric acid was added. When digestion was complete and the substance got dried on a hot plate, it was further treated with 2 aliquots of conc. HNO_3 (2 ml each time). When all the NO_2 was expelled and the residue became dry, a drop of conc. HCl was added and the whole residue was dissolved in 0.1 *N* HCl, heated to boiling, cooled and then made up to 10 ml in each case. Known standards and blanks were similarly treated and all samples were analysed by atomic absorption spectrophotometry.

In the present study only a few selected stations at pre-determined depths were sampled. The station number, their sampling depths and concentration of different metals in dissolved and particulate forms are given in Table 1. Average values of metals along with standard errors are also given in Table 1.

At 10 m depth (surface) most of the metals were higher at st 857, away from the islands, than at the stations close to the islands. This shows that there is no land influence on the metal concentration. The concentration of dissolved Fe at 500 m depth at st 857 was almost double the average concentration of Fe at the same depth at the stations around the islands. The concentration of dissolved Mn at 500 m depth at st 857 was almost half the average concentration of Mn at the same depth at the other stations.

Dissolved oxygen at all stations decreased with depth reaching its minimum at 500 m. The concentrations of Fe had a similar distribution. The average concentration of Fe at 1000 m depth at most of the stations was greater than that at 500 m depth (Table 1).

The present data are insufficient to correlate the concentrations of different metals to their chemical speciation. Hence, it is not possible to discuss the chemistry of metals under study. However, a tentative prediction can be made of their speciation, considering the values of the dissolved and the particulate forms of the metals, the temperature, salinity, dissolved oxygen and *p*H of the water.

The average concentration of Cu was found in the upper layer (10 m depth) to be nearly 13.3 ± 1.1 μg/litre and no particular pattern in its distribution was observed with depth. The values were, however, well within the range 0.2-22 μg/litre given by Pytkowicz and Kester[2] for sea water. Dissolved copper is controlled by the redox conditions of the sea water[3], as the solubility of complexes depends on redox conditions.

At most of the stations, dissolved Cu was higher towards the upper layers than in the middle layers (Table 1), indicating that the release of Cu occurs due to organic decomposition towards the surface and that optimum redox conditions are lacking in the middle layers. The concentration of particulate Cu was appreciable in deeper layers than in the upper layers. Due to metal$-H_2O-CO_2$ system about the coral base, which renders carbonates stable solid phases, the material in suspension is enriched with the metal. This explains the higher surface value for Cu, 13.3 ± 1 μg/litre, compared to an earlier reported value 4.7 ± 0.4 μg/litre in the Arabian Sea[4] in the same season.

The average concentration of dissolved Fe at stations around the islands was 25.3 μg/litre whereas that at st 857 was 36.5 μg/litre. Higher concentration of dissolved Fe further away from the islands and lower values of particulate Fe correspond with the low oxygen value observed away from the islands. At almost all stations in the Laccadive Sea, higher concentrations of particulate Fe indicate the predominance of colloidal Fe^{3+} and organic matter, for the concentration of Fe present in sea water is a measure of organic matter[5]. An increase in the concentration of dissolved iron was observed at 500-1000 m depth region, in accordance with the low oxygen concentration present at this depth range. Fe

Table 1—Concentrations of Metals along with Average and SE Values in Dissolved and Particulate Form in the Laccadive Sea with the Corresponding Oxygen and *p*H Values

[Metal concentrations expressed in μg/litre (dissolved form) and μg/g (particulate form)]

Depth m	Dissolved oxygen ml/l	*p*H	Cu		Fe		Mn		Zn		Co		Ni	
			D	P	D	P	D	P	D	P	D	P	D	P
St 857 (12°13.5′N, 72°22′E)														
10	4.09	8.17	16.1	420	36.5	1422	16.6	271	29.7	3085	1.3	—	13.1	203
100	2.80	8.1	5.6	162	14.5	2125	23.4	284	4.7	1178	1.1	—	7.5	87
250	0.49	7.8	4.6	656	85	—	75	46	1.2	147	ND	42	1.3	24
500	0.29	7.78	11.9	533	55.5	583	20.8	89	8.7	516	ND	ND	16.1	13
St 867 (10°05′N, 72°56′E)														
10	4.58	7.93	19.9	146	43.2	2104	13.5	130	8.4	3901	ND	ND	16.3	38
100	3.63	7.91	5.7	22	27	751	16.2	24	1.9	309	6.7	ND	1.9	ND
500	0.67	7.47	12	11	10.5	873	23.7	30	3.0	155	2.2	ND	2.0	58
1000	0.54	7'45	15.7	411	26.7	692	40.2	24	11.0	1086	1.9	ND	1.9	138
St 869 (9°16.5′N, 72°35′E)														
10	5.19	8.23	9.4	130	18.6	2116	7.7	107	4.6	580	5	86	2.7	46
100	3.85	8.19	3.9	51	17.2	430	37	129	3.2	467	ND	ND	ND	54
500	0.47	7.72	13.4	240	10.8	909	80	80	13.6	224	3.8	144	7.0	ND
1000	0.66	7.69	6.9	328	96	4600	28.7	84	9.7	1280	1	ND	5.6	152
St 871 (8°32′N, 73°26.5′E)														
10	4.64	8.14	—	32	—	7603	—	192	—	92	—	ND	—	127
100	3.14	8.07	3.7	35	13	1798	3.8	28	1.8	4356	ND	ND	0.6	44
500	0.59	7.68	2.1	48	28.2	1648	26.7	55	4.9	1128	ND	ND	ND	35
1000	0.91	7.66	1.9	118	15.7	2121	41	94	11.2	768	ND	74	3.9	16
1500	1.59	7.67	8.9	67	21	2622	12.3	64	2.0	599	1.7	30	2.7	72
St 873 (9°26′N, 73°45′E)														
10	5.42	8.2	8.0	87	14.2	2584	10.3	349	2.9	765	ND	74	8.2	70
100	4.18	8.13	16.9	18	25.2	1133	5.2	63	4.7	446	ND	ND	2.7	34
500	0.62	7.62	2.1	—	49.5	2557	41.5	80	6.0	840	ND	ND	1.3	18
1000	1.06	7.62	6.9	76	35.2	2765	1.8	106	7	583	ND	ND	3.4	ND
1500	2.06	7.62	8.1	169	8.5	1338	2.0	53	9	1045	ND	ND	4.0	123
2000	—	—	3.4	66	10.5	1402	2.7	15	8.5	609	ND	100	2.5	52
Average values with SE														
10	4.78 ±0.31	8.13 ±0.14	13.3 ±1.1	163 ±5	28.1 ±1.7	3166 ±21	12 ±0.9	210 ±4	11.4 ±1.6	1685 ±17	ND	ND	10.1 ±1.1	97 ±3
100	3.52 ±0.31	8.08 ±0.14	7.2 ±1	58 ±3	19.4 ±1.1	1247 ±9	17.1 ±1.6	106 ±4	33 ±0.5	1351 ±17	ND	ND	2.5 ±0.7	44 ±2
500	0.47 ±0.16	7.65 ±0.14	8.3 ±1	208 ±7	30.9 ±1.9	1314 ±12	38.5 ±2.1	67 ±2	7.2 ±0.8	573 ±9	ND	ND	5.3 ±1.1	25 ±2
1000	0.70 ±0.18	7.60 ±0.13	7.8 ±1.1	233 ±5	43.4 ±2.6	2544 ±17	27.9 ±2	77 ±2	9.7 ±0.6	929 ±7	ND	ND	3.7 ±0.6	76 ±4

ND, not detectable; D, dissolved; P, particulate; SE, standard errors

occurs in the form of Fe^{2+} and Fe^{3+}. However, in the sea, Fe^{2+} gets converted to Fe^{3+} by dissolved oxygen and under alkaline conditions, Fe^{3+} appears either in a soluble complex or in colloidal form[6]. Mn on the contrary exists in Mn^{2+} and Mn^{4+}. The oxidation of Mn^{2+} to Mn^{4+} by dissolved oxygen appears to be slow under weak alkaline conditions. The study of both Fe and Mn has received a greater attention among the heavy metals because they have a tendency to form hydrous oxides with dissolved oxygen in the presence of water and these hydrous oxides are the chief carriers of the other heavy metals like Zn, Co, Ni, Cu[6].

The average concentration of dissolved Mn at the surface increased with depth, and the highest value was recorded at 500 m and 1000 m depth (Table 1). At st 873, low concentration of dissolved Mn was observed at all depths except at 500 m (Table 1). At depths > 1000 m, very low concentrations of dissolved Mn were found showing that in deeper layers redox conditions are not optimum to bring Mn into soluble form. The concentration of dissolved metals are also likely to be controlled by insoluble carbonates. Particulate Mn was appreciably lower than particulate Fe at all depths and at all stations.

Zn concentrations at stations nearer to the islands were lower than at the station away from islands.

Highest concentration of dissolved Zn was at st 857 (29.7 μg/litre). Surface values of dissolved Zn ranged from 2.9-29.7 μg/litre. This range is lower than that observed earlier in the Arabian Sea[4]. Particulate zinc made a significant fraction in the Laccadive Sea. Except at st 857, dissolved Zn was significantly lower at the surface than in deeper waters. Zirino and Yamamoto[7] observed that Zn speciation is markedly *p*H dependent. At *p*H 8.1 $Zn(OH)^{\circ}$ is the predominant form whereas Zn^{2+} is found when the *p*H is lower than 7.8.

At most of the stations Co was below the detection limit of the method used. However, in the Laccadive Sea both dissolved,and particulate,Co was below the detection limit. Dissolved Ni concentrations at surface ranged from 13.1-16.3 μg/litre whereas its value in particulate form was greater.

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Biochemical Studies on Zooplankton from the Laccadive Sea (Lakshadweep)

ROSAMMA STEPHEN, S U PANAMPUNNAYIL, T C GOPALAKRISHNAN & V N SANKARANARAYANAN
National Institute of Oceanography, Regional Centre, Cochin 682 018

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Carbohydrate, protein and lipid were estimated in copepods, euphausid sp. and mysid sp. collected from the Laccadive Sea. Protein formed the major biochemical constituent followed by lipid. Carbohydrate content was the least (<6%). The differences in various biochemical components of neritic and oceanic forms were negligible.

The assessment of secondary production from marine ecosystem necessitates the study of physiology and biochemistry of zooplankton along with the information on biomass and species composition. Considerable information is available on the above aspects of zooplankton from temperate, boreal and polar seas[1-7]. Very few reports are available on the biochemistry of tropical zooplankton. Bogorov *et al.*[8] have discussed the biochemistry of Indian Ocean plankton. Nair *et al.*[9] and Gopalakrishnan *et al.*[10] have studied the biochemistry of neritic zooplankton organisms of the Cochin region.

Biochemical composition of some dominant zooplanktonic groups from the Laccadive Sea, collected during the 31st cruise (March-April 1978) of *R V Gaveshani* is presented in this paper.

Zooplankton were collected by vertical hauls (200 m to surface) using an IOS net[11], and were frozen immediately at −10°C in a deep freeze. Biochemical analysis was carried out later in the laboratory. Copepods (*Euchaeta marina*, *Undinula vulgaris*), mysids (*Siriella* sp.) and euphausids (*Euphausia diomediae*) were the dominant groups present in the samples. Adult animals were sorted out after thawing the samples for the determination of various biochemical constituents. Excess water from the specimens was removed gently by a filter paper before determining their wet weight. In order to compare the present results with the published data, the values were converted into constituents on a dry weight basis. Drying to constant weight was done by keeping the animals in an oven at 70°C.

The major biochemical constituents, viz. carbohydrate, protein and lipid were estimated using the method described by Raymont *et al.*[2] and the results are given in Table 1. Triplicate analysis was made and the average value taken. Owing to the small number of specimens only carbohydrate, protein and lipid fractions were estimated and the values for ash and chitin together were calculated from the difference.

The carbohydrate content was low in all the organisms with a maximum of 5.13% in copepod, *Euchaeta marina* and 4.65% in mysids, *Siriella* sp. As in all zooplankton species so far investigated from different marine areas[7] carbohydrate was the lowest. Nair *et al.*[9] reported the carbohydrate content of copepods from Cochin backwater as 3.8% and 2.7% for mysids which are slightly lower than the present values. Their observations are on *Acartia* sp. from the Cochin backwater, an environment which is subjected to varying hydrographic conditions, whereas the present study is on *Undinula vulgaris*, *Euchaeta marina* and *Oncaea* sp., which are mainly oceanic. The higher values noted may be due to the variation in the species and in the environment. Gopalakrishnan *et al.*[10] reported 4.1% of carbohydrate for *Acartia* sp. from the same area, which is higher than the average values

Table 1—Carbohydrate, Protein and Lipid Contents in Different Zooplankton Species

[Values, average, are expressed as per cent dry weight]

Group	Carbo-hydrate	Protein	Lipid
Copepods (Calanoida; *Euchaeta marina* and *Undinula vulgaris*)	2.58	59.35	24.56
do	2.5	61.92	24.78
Euchaeta marina	5.13	53.33	25
Cyclopoida (*Oncaea* sp.)	5.1	57.18	23.33
Euphausid (*Euphausia diomediae*)	2.55	60	31.77
Mysid (*Siriella* sp.)	4.65	59.03	21.75

(2.54%) reported here for copepods in general and less than that of for *Euchaeta marina* (5.1%).

Raymont *et al.*[2] reported low carbohydrate content (av. 2.3%) for *Neomysis integer* and for decapods from Southampton waters which is comparable with the values obtained here (2.55%) for euphausids. Eventhough copepods which feed on phytoplankton could obtain carbohydrate directly, the lower carbohydrate content suggests that glycogen, the usual storage form of carbohydrate, did not form a substantial part of the body reserve. The same feature was observed by Raymont *et al.*[7] for certain zooplanktonic organisms.

Vinogradov[1] reported widely varying carbohydrate content (6 to 28%) in *Euphausia superba*. Similarly Vinogradov[12] observed relatively high carbohydrate content (16 to 34% by dry weight) for general plankton taken from the Black Sea and a rather low carbohydrate content (9%) for *Calanus helgolandicus*. But in all these determinations the carbohydrate was not analysed directly indicating the possibility of overestimation.

The present investigation showed relatively high protein content in all the organisms and the values are comparable with those reported by Nair *et al.*[9]. The values reported (55.5%) by Gopalakrishnan *et al.*[10] for *Acartia* sp. from Cochin backwater were slightly lower than the present values. The variability in the protein content may be due to the fact that it is utilized as a metabolic substrate[13]. Raymont[13] also reported variation in protein with variation in environmental salinity. For cold water zooplanktonic forms protein values varying between 30 and 83% were reported and the highest value was observed in the marine copepod *Acartia clausi*[14]. Raymont *et al.*[2] reported an average protein value of 71% for *Neomysis integer* from the Southampton waters. Vinogradov[12] reported 40 to 60% protein for general plankton with 43% for *Calanus* and still higher values (>50%) for mysids. Raymont *et al.*[7] found a mean value of 57% for the euphausid *Meganyctiphanes norvegica* which compared well with the values obtained for euphausid species (60%) from the Laccadive Sea.

Fisher[15] reported an average lipid content of 5 to 70% for *Euphausia krohnii* from the North Atlantic. Conover[16,17] observed around 60% for the cold water copepod *Calanus hyperborius*. Raymont *et al.*[5] reported variations in the lipid content (6 to 36%) of the euphausid *Meganyctiphanes* with season and body size. The present values for lipid (Table 1) compare well with those reported by Raymont[13]. Gopalakrishnan *et al.*[10] reported lipid content of 18.6% for copepods in general and 25.3% for *Acartia* sp. from the backwaters of Cochin. The lipid values for the oceanic forms reported here did not vary much with those of neritic forms.

The present study indicates that the variations in the different biochemical constituents between the neritic and oceanic forms are not appreciable. Protein forms the major biochemical constituent of the zooplankton as reported from other areas. These organisms have no extensive lipid stores and the carbohydrate reserve is very little.

The authors express their gratitude to Dr S.Z. Qasim, Director, for his interest and encouragement.

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Karyology of the Genus *Labidocera* Lubbock from the Laccadive Sea (Lakshadweep)

USHA GOSWAMI & S C GOSWAMI
National Institute of Oceanography, Dona Paula, Goa 403 004

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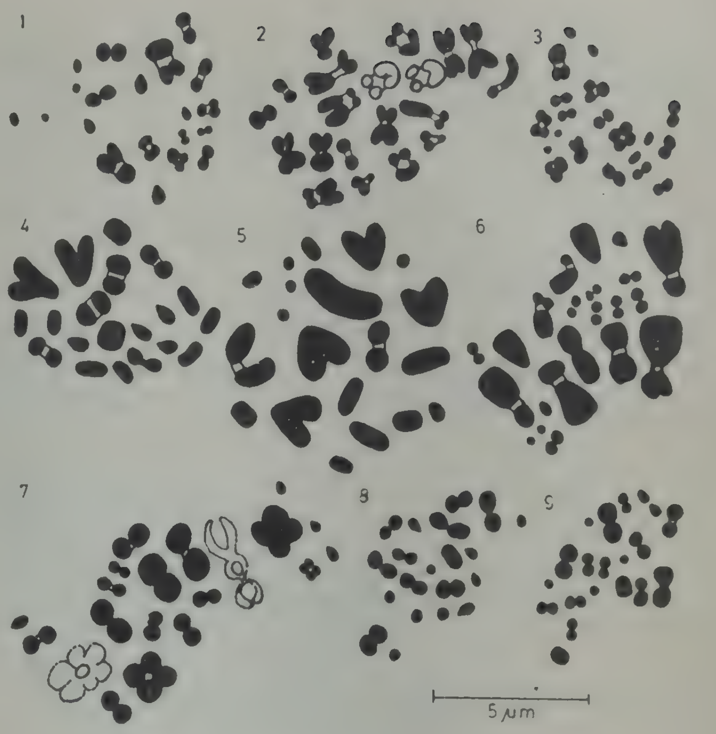
Labidocera euchaeta, L. laevidentata, L. pseudacuta, L. acutifrons, L. bataviae, L. madurae, L. bengalensis and *Labidocera* sp., collected from the Laccadive Sea during the 31st Cruise of *R V Gaveshani*, possess a diploid number of 20 chromosomes while *L. minuta* possesses 22. On the basis of similarities and dissimilarities of the karyotypic details, cytotaxonomic relationship has been derived and discussed at the intrageneric and interspecific levels.

Details of the karyotype in various genera of copepods have been utilized earlier in resolving systematic anomalies and in establishing intra and intergeneric relationship[1-4]. The present communication gives an account of the diploid complements of chromosomes of 9 species of the genus *Labidocera* (Pontellidae, Calanoida, Copepoda). From the morphology of the chromosomes, cytotaxonomic interspecific relationship has been derived.

Karyotype studies have been made on *Labidocera euchaeta* Giesbrecht, *L. laevidentata* Brady, *L. pseudacuta* Silas and Pillai, *L. acutifrons* Dana, *L. bataviae*, A. Scott, *L. minuta* Giesbrecht, *L. madurae* A. Scott, *L. bengalensis* Krishnaswamy and *Labidocera* sp. Zooplankton samples were collected from the surface using a square net (mouth area 0.25 m^2, mesh width 0.3 mm) on board *R V Gaveshani* during the 31st Cruise (March-April 1978) from stations 856-871 lying between lat. 8° to 14°N and long. 71° to 74°E in the Laccadive Sea. The various environmental parameters were as follows: salinity, 34.5-35.64 $^{\circ}/_{oo}$; temperature, 28.5°C-30.5°C; dissolved oxygen, $+4 - +12\%$. The material after filtration was fixed in acetic alcohol (1:3) and preserved in 70% alcohol. Male specimens were sorted out and stained in acetic orcein. Squash preparations were made from the gonads and karyotypic details were studied.

Number and shape of chromosomes—The diploid number of chromosomes encountered during the spermatogonial metaphases was 20 in all species studied except in *L. minuta* where it was 22 (Figs 1-9). The diploid karyotype formulae are given in Table 1. Metacentrics dominate in numbers in all the species, e.g. in *L. pseudacuta, L. acutifrons* and *L. madurae* these were 16; in *L. bataviae* and *Labidocera* sp., 14; in *L. euchaeta* 12; and in *L. laevidentata* and *L. bengalensis* 10 in number.

The morphology of the chromosomes was identical in all species studied. Acrocentrics were either rod-shaped with one end pointed or dot shaped (Fig. 10). In *L. laevidentata* alone, the acrocentric pair showed a small arm. The metacentrics were dumb-bell, V-, and rod-shaped with both ends rounded. Sub-metacentrics were though rod and J-shaped, the centromeric gap was often visible. The sister-chromatids of the chromosomes were usually seen apart.



Figs 1to9—Spermatogonial metaphases of *Labidocera euchaeta* (1), *L. laevidentata* (2), *L. pseudacuta* (3), *L. acutifrons* (4), *L. bataviae* (5), *L. minuta* (6), *L. madurae* (7), *L. bengalensis* (8), and *Labidocera* sp. (9)

Chromosome size—The average total length (μm) of the homologous pairs was in the range of 0.9-2.1, *L. laevidentata;* 0.3-1.05, *L. pseudacuta;* 0.6-3, *L. acutifrons, L. madurae* and *L. bataviae;* 0.3-1.5, *L. bengalensis, L. euchaeta* and *Labidocera* sp. respectively. Average total length of the individual homologous pair is given in Table 1. The diploid chromosomal set of each species could distinctly be catagorized into small and large groups (Fig. 10). The acrocentrics mainly belonged to the former group.

Sex chromosomes—In all the species studied, only in *L. laevidentata* and *L. madurae*, the sex-chromosomes could be identified because of the differential staining behaviour (Fig. 10).

Cytotaxonomical interspecific relationship—Silas and Pillai[6] have reported the occurrence of 23 species belonging to the genus *Labidocera* from the Indian Ocean and adjacent waters. Of the 9 species described here, *L. acutifrons, L. euchaeta, L. bengalensis, L. pavo, L. bataviae* and *L. kroyeri* seem to be the first records from the Laccadive Sea. Karyologically, 14 species have so far been described including the present ones[2,3]. The details of the karyotypes along with the similarities of taxonomic characters of the species investigated have been utilized to trace the cytotaxonomical relationship on the interspecific and intrageneric levels, e.g. karyologically all the species of

Table 1—Karyotype Formula, Average Total Length of Homologous Pairs (μm) and Position of Centromere in the Species Investigated

Species (karyotype formula)	Chromosomal pairs										
	1	2	3	4	5	6	7	8	9	10	11
L. euchaeta (12M+8A)	1.5M	1.2M	1.2M	0.9M	0.9M	0.6M	0.6M	0.6M	0.45M	0.3A	—
L. laevidentata (85M+10M+2A)	2.1SM	1.8SM	1.65SM	1.5SM	1.5M	1.2M	1.2M	1.2M	1.2M	0.9A	—
L. pseudacuta (16M+4A)	1.05M	1.05M	0.9M	0.9M	0.9M	0.9M	0.9M	0.6M	0.45A	0.3A	—
L. acutifrons (16M+4A)	3M	1.2M	1.2M	1.2M	1.05M	0.9M	0.9M	0.9 M	0.6A	0.6A	—
L. bataviae (16M+4A)	3M	2.4M	2.4M	1.8M	1.2M	0.9M	0.9M	0.9M	0.6A	0.6A	—
L. minuta (65M+10M+6A)	3SM	2.4SM	1.8M	1.5M	1.2M	1.2M	1.2M	1.2M	1.2A	0.6A	0.30A
L. madurae (16M+4A)	3M	2.1M	1.8M	1.8M	1.5M	1.5M	1.5M	1.2M	0.75A	0.6A	—
L. bengalensis (10M+10A)	1.5M	1.2M	1.2M	0.9M	0.9M	0.6A	0.6A	0.6A	0.6A	0.3A	—
Labidocera sp. (14M+6A)	1.5M	1.2M	1.2M	0.9M	0.9M	0.9M	0.9M	0.75M	0.6A	0.3A	—

SM = submetacentric; M = metacentric; A = acrocentric

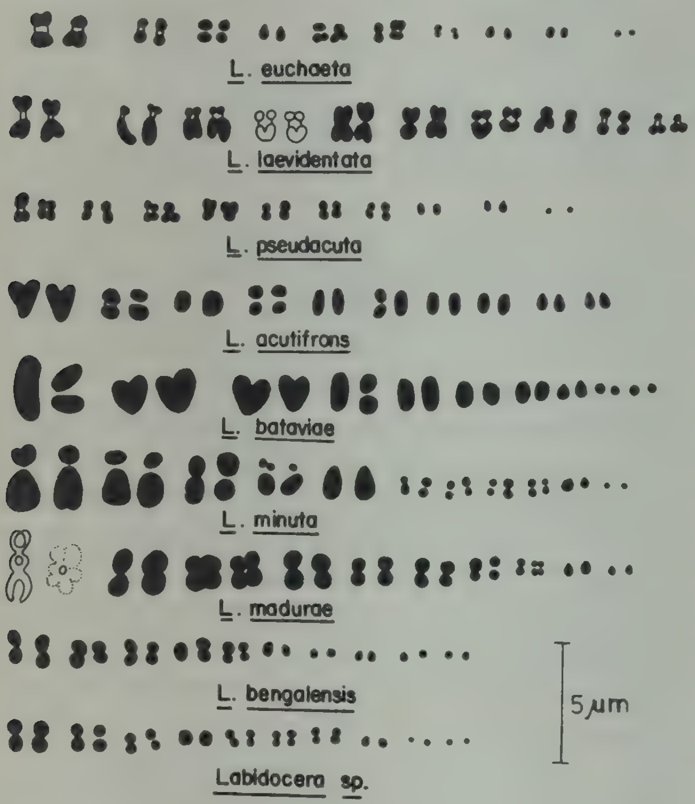


Fig. 10—Karyograms of various species investigated

the genus *Labidocera* possess 2n=20 (except *L. minuta*), dominance of the metacentrics in the karyotypes, similar shape of the metacentrics in the karyotypes, similar shape of the chromosomes and similar sex mechanism. Taxonomically, also all of them possess similar generic characters. These similarities both in taxonomic and karyologic characters justify their placement under the same genus *Labidocera*. However, in details, each karyotype is quite distinct from the other. This feature supports their individuality on the species level.

Silas and Pillai[5] taxonomically described a new species of *Labidocera*, viz. *L. pseudacuta* which was earlier treated as a variety of *L. acuta*[7,8]. In view of the morphologic similarities, these authors felt *L. acuta* and *L. pseudacuta* were closely allied species having the same ancestors. They further remarked that the former was distributed in the neritic regions of the Indian Ocean, whereas, the latter was oceanic.

Cytologically also, these 2 species possess similar generic characters, which reflect their common origin at some stage of their evolution. However, the details of the karyotype fall quite wide apart e.g. *L. acuta* collected from the Mandovi-Zuari estuaries and studied earlier[2] has all the chromosomes metacentric within a size range of 0.84 to 0.86 μm. But in *L. pseudacuta*, the karyotype formulae includes only 16 metacentrics and 4 acrocentrics. The size range is also larger (0.3-1.05 μm). Hence on cytotaxonomical basis also, we feel that *L. pseudacuta* and *L. acuta* should be treated as 2 separate species and not varieties of the same (*L. acuta*).

Similarly, Silas and Pillai[6] while giving the taxonomic details of various species belonging to the genus *Labidocera*, have remarked that *L. pavo* was closely allied to *L. bataviae* and *L. madurae*. Karyologically, the latter 2 species show some closeness on the species level, e.g. the presence of the same chromosome number (2n=20), karyotype formulae (16M+4A) and the size range of the chromosomes (0.6-3 μm). But *L. pavo* possesses all the chromosomes metacentric within a size range of 0.84-1.48 μm. In fact, *L. acutifrons* not mentioned by Silas and Pillai[6] as closely allied species show more chromosomal similarities to *L. bataviae* and *L. madurae*. The details of the karyotype are quite similar. Therefore, based on cytotaxonomic evidences, it is ascertained that *L. bataviae*, *L. madurae* and *L. acutifrons* are closely related species. Their speciation has occurred probably by some submicroscopic chromosomal changes which led to genetic change.

Modal chromosome number—In all 14 species analysed, cytologically 13 possess a diploid number of 20 and haploid number of 10 chromosomes and 10 (1 n) is the modal number of this genus.

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Further Observations on Gaveshani Bank

S Z QASIM
National Institute of Oceanography, Dona Paula, Goa 403 004

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During the 31st cruise, *R V Gaveshani* made 4 runs over the bank in different directions. From the echograms obtained it became possible to draw an outline of the bank. Physical and chemical features over the bank were similar to those of the upper layers of the Laccadive Sea. Sediments taken from the bank consisted of calcareous sand with fragments of live corals, calcareous algae and a large number of animals typical of coral reef environment.

A bank with living corals, named as Gaveshani Bank[1], has been reported from the west coast of India. During the 31st cruise of *R V Gaveshani* (March-April 1978) the ship once again visited the Gaveshani Bank on 5th April 1978. Since the exact position of the bank was noted earlier by a satellite fix, the bank was located with ease.

The ship made 4 runs over the bank, from one extremity to the other, at a speed of about 2-3 knots to determine the size and shape of the bank. The 1st run was from SE to NE direction, the 2nd from N to W, the 3rd from W to S and the 4th from W to E. During the run echograms were taken using echosounders and sonar. From the several echograms thus obtained a generalized sketch of the bank was obtained (Fig. 1).

The bank has NW-SE orientation. It is about 770 m long and 330 m broad. The depth over the bank ranges from 32 to 40 m and the shallowest point is at the apex[1]. Table 1 gives some of the physical and chemical features over the bank. The average Secchi disc reading over the bank was 16 m, which from the equation $k = \frac{1.7}{D}$ gave the value of attenuation coefficient of light (k) as 0.106 and the compensation depth of the euphotic zone (1% of the surface illumination) at about 48 m. This means that the entire bank is within the photosynthetic (euphotic) zone. Other features over the bank (Table 1) were typical of the upper 0-30 m of the Laccadive Sea.

Measurements of primary production, chlorophyll *a*, phaeophytin and particulate organic carbon over the bank are given in Table 2. ^{14}C uptake and chlorophyll *a* values were low and the particulate organic carbon was relatively high. These features were also similar to those of the Laccadive Sea. The general composition of

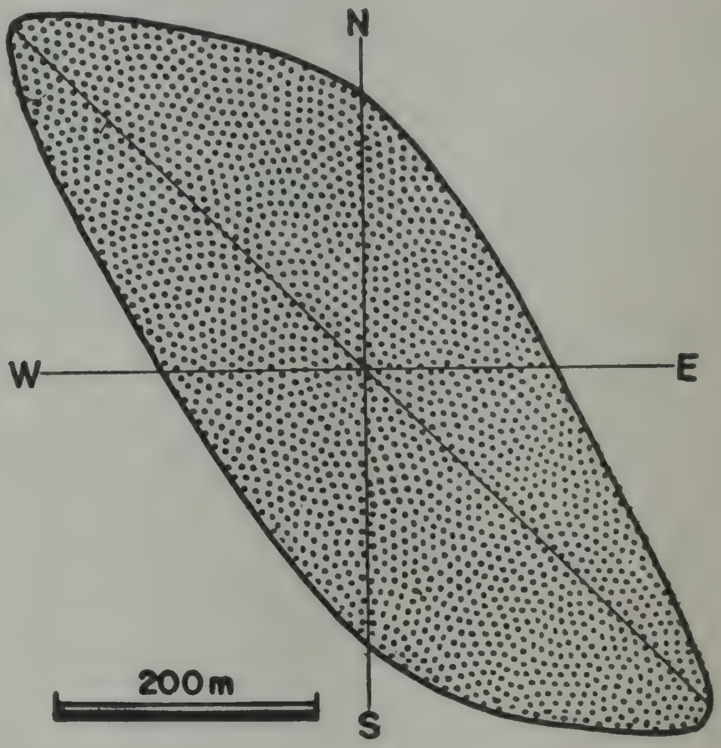

Fig. 1—Outline of Gavesnani Bank drawn from the echograms obtained during the 31st cruise

Table 1—Physical and Chemical Features over the Gaveshani Bank on 5th April 1978

Depth* m	Temp. °C	Salinity ‰	Oxygen ml/l	*p*H	PO$_4$-P μg-at/l
0	29.11	35.36	4.8	8.21	0.3
10	29.99	35.35	4.61	8.22	0.24
20	28.97	35.36	4.54	8.22	0.24
30	28.93	35.35	4.52	8.22	0.24

*NO$_3$-N not detected at any depth

Table 2—Primary Production and Other Related Aspects in the Water Column over the Bank

	Surface	Water column 0-30 m
^{14}C uptake	0.26 mgC/m^3/hr	9.7 mgC/m^2/hr
Chlorophyll *a*	0.14 mg/m^3	2.49 mg/m^2
Phaeophytin	0.02 mg/m^3	0.48 mg/m^2
Particulate organic carbon	12 mg/m^3	0.41 g/m^2

phytoplankton at the surface and 30 m depth is given in Table 3.

The abundance of *Trichodesmium* is a seasonal phenomenon and occurs from February to May in coastal waters[2]. Zooplankton haul made by the IOSN at about 1100 hrs, from 36 m depth to the surface, gave the following results:

Biomass of zooplankton was 0.066 ml/m^3 with copepods 5250, decapod larvae 26, chaetognaths 560, fish larvae 5 per haul of IOSN from 36 m to the surface. This indicates that in the water column (0-36 m) above the bank, zooplankton organisms are sparse.

A few grab samples from the bottom showed that the sediment was typical of coral bank with coarse calcareous sand and many species of calcareous algae and fragments of live and dead corals. The samples contained a large number of animals. Some of these were identified as *Favia* sp., *Cyprea* sp., *Umbonium* sp., *Arca* sp., *Harmothoe* sp. and *Metagrapsus* sp. The samples also included many nudibranchs and other animals which could not be identified.

It appears that this bank is very similar to some of the submerged banks of the Laccadive Archipelago with the only difference that like the Angria Bank off Ratnagiri, it is located closer to the mainland. The occurrence of this bank raises the possibility of the existence of many more coral banks, probably with living corals, hitherto unreported from the west coast of India.

Table 3—Phytoplankton Component in the Water Column above Gaveshani Bank

At surface		At 30 m depth	
Component	Cells or filaments/litre	Component	Cells/litre
Trichodesmium sp.	750	*Amphora* sp.	500
Coscinodiscus sp.	300	*Navicula* sp.	800
Navicula	1050	*Coscinodiscus* sp.	100
Nitzschia	300	*Peridinium* sp.	400
Peridinium	900	*Prorocentrum* sp.	200
Flagellates	300	Flagellates	600

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Wave Characteristics in the Western & Northwestern Bay of Bengal during the Southwest Monsoon of 1978

P V SATHE, Y K SOMAYAJULU & V V GOPALA KRISHNA
National Institute of Oceanography, Dona Paula, Goa 403004

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Wave data are analysed for significant wave height (H_s), R.M.S. wave height (H_{rms}), maximum wave height (H_{max}), zero-crossing period (T_z), average period (T_c) and spectral width parameter (E). A scatter diagram relating H_s and T_z is also presented. The range of H_s is wide varying within 30 and 220 cm while T_z is confined to 6 to 15.5 sec, with a maximum occurrence between 6.5 and 8 sec. The percentage occurrence of E indicates that T_z has exceeded T_c in most of the cases.

The data available on waves are very sparce in the Indian Ocean, being restricted to a few coastal places[1-3]. In recent years some wave atlases[4,5] for the Indian Ocean have been published utilising the Indian Daily Weather Reports (IDWR). Since these data are only visual observations, they are not very suitable to arrive at a comprehensive picture of different wave characteristics.

Materials and Methods

During the 37th to 40th cruises of *R V Gaveshani* in the southwest monsoon of 1978 (August and September) wave data were collected at 64 stations between 10° and 21° N and 80° and 90° E (Fig. 1) using a shipborne wave recorder. The wave recorder, designed and developed by the Institute of Oceanographic Sciences UK, is a modified version of the one earlier developed by Tucker[6]. The instrument was operated at 15 min at each station where the ship was stopped for hydrographic observations without anchoring. Station depths varied from 30 to > 3000 m. A typical wave record is given in Fig. 2.

Wave records were analysed in accordance with the method suggested by Draper[7]. All the heights were corrected for depth attenuation effect. The following parameters were evaluated from each record—(i) height of the highest crest, A; (ii) depth of the lowest trough, B; (iii) number of zero-crossings, N_z; and (iv) number of crests, N_c.

Significant wave height (H_s) was obtained from the values of A, B and N_z. The R.M.S. wave height (H_{rms}) was calculated from the relation,

$$H_{rms} = 1/2\, H_1 (2\theta)^{-1/2} (1 + 0.289\theta^{-1} - 0.247\theta^{-2})^{-1}$$

where, $H_1 = (A + B)$ and $\theta = \ln N_z$.

The heights of H_s, H_{rms} and H_{max} are shown in Fig. 3 in the form of percentage exceedance curves.

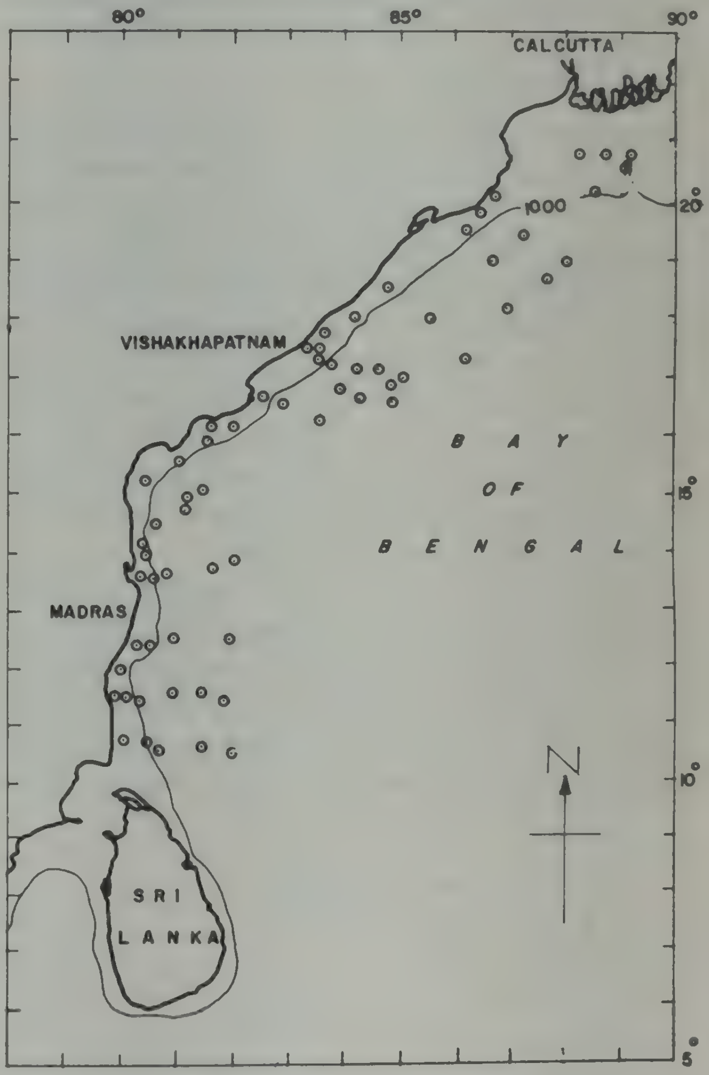

Fig. 1—Location of stations

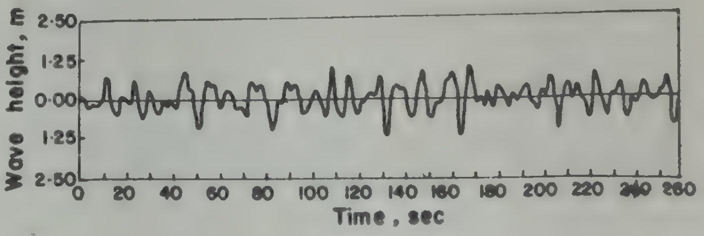

Fig. 2—A typical wave record

Logarithmic scale is chosen along X-axis to reduce the size of the figure.

Percentage occurrence of zero-crossing period (T_z) is shown in Fig. 4 at intervals of 1/2 sec. The spectral width parameter (E) was determined by the relation[8]

$$E^2 = 1 - \left[\frac{T_c}{T_z}\right]^2$$

The average period (T_c) used in this relation refers to all waves in a record irrespective of whether they cross zero-line or not; whereas the zero-crossing period T_z is the average period of exclusively those waves which cross zero-line. Fig. 5 shows the distribution of spectral width parameter as percentage occurrence for different ranges of values.

Scatter diagram relating H_s and T_z for 59 out of 64 stations is presented in Fig. 6. The number of occurrences for wave height are selected in the range of 25 cm each and for the period of 1 sec interval.

Results and Discussion

Cumulative distribution of wave heights (Fig. 3) indicates the percentage of wave heights exceeding a particular value during the entire span of observations. For example in 80% of cases H_s exceeds 60 cm whereas in no case it exceeds 225 cm (i.e. highest recorded value of H_s is <225 cm). For each range of wave height the values of H_{rms} are very low compared to H_s or H_{max} and the highest value of H_{rms} is not > 50 cm while majority of values of H_s or H_{max} are > 50 cm. The low value of H_{rms} compared to H_s or H_{max} indicates that although a few high waves are always associated with each record, the overall wave heights are very low.

It is seen from Fig. 4 that periods between 6.5 and 8 sec are abundant, the most frequent period being 6.5-7 sec. A secondary mode of periods is found between 10 and 11 sec while periods between 13.5 and 14 sec are absent. Fig. 6 indicates that the values of wave heights and wave periods are widely spread over the entire range. This may be because a very large area of the Bay was covered during the cruises. It may also be attributed to the fact that these observations were

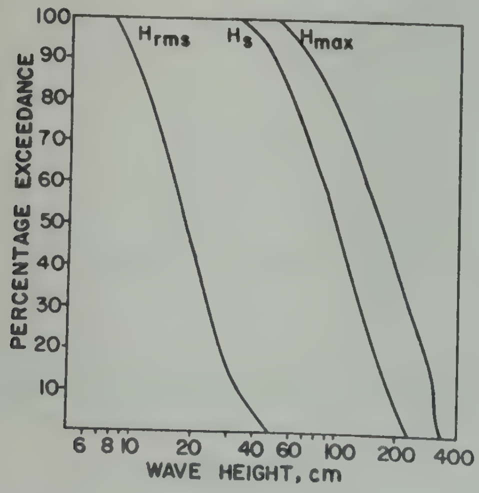

Fig. 3—Cumulative distribution of R.M.S. wave height, significant wave height and maximum wave height

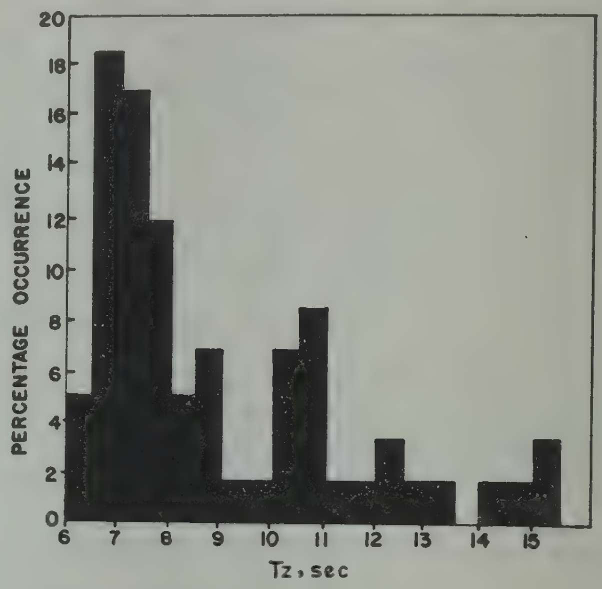

Fig. 4—Distribution of zero-crossing period

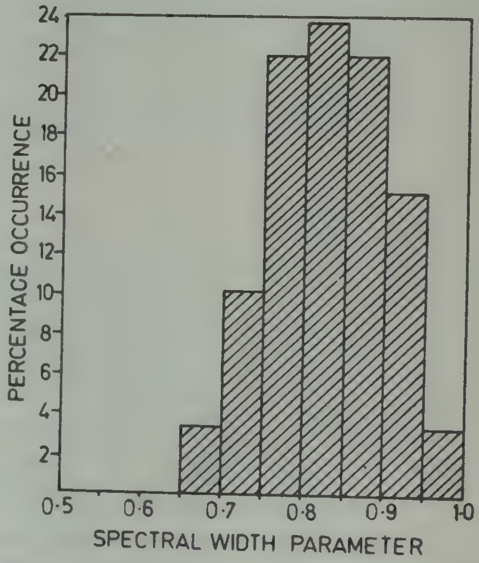

Fig. 5—Distribution of spectral width parameter

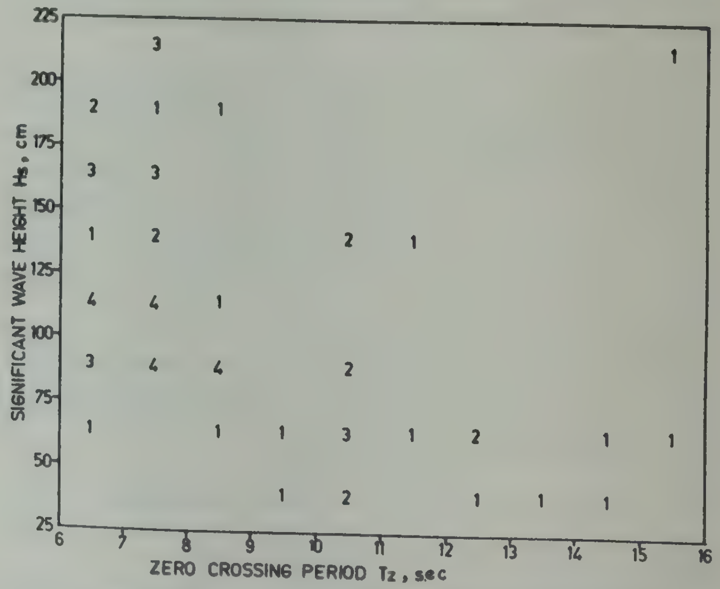

Fig. 6—A scatter diagram relating significant wave height to zero-crossing period

made during monsoon. It may be mentioned here that even though the winds were predominantly from south and southwest, their speeds varied over a wide range (calm-40 knots). Such fast changing conditions of the wind field may also be generating waves of various periods and heights. However, it is seen in Fig. 6 that 31 out of 59 stations (53%) are having periods between 6 and 8 sec. Incidentally this range of periods (6 to 8 sec) happens to be the dominant one as already revealed in Fig. 4. Similarly another small group of 9 values (16%) is confined to a range of periods between 10 and 11 sec. The scatter diagram also shows that usually waves with high values of H_s are associated with low values of T_z. There is only one case (at 22°52′N and 89°09′E) where unusually long period waves (15.3 sec) had a high value of H_s (205 cm).

Statistical distribution of wave heights can reasonably be represented by a spectral width parameter (E). The value of E (which varies between 0 and 1) is determined by the relative magnitudes of T_c and T_z. For example if in a given situation a wide range of wave heights is present, T_z becomes far greater than T_c. Since many wave components may not be crossing zero-line, the resulting E in this case is nearing unity. However, if wave heights are confined to a small range, the result is a usual swell and most of the waves cross the zero-line. In this case T_z does not differ much from T_c and E is close to zero.

It is seen from Fig. 5 that there is no value < 0.65 and the highest occurrence lies between 0.8 and 0.85. This shows that the spectral width parameter is nearing one. We may conclude from this diagram that the monsoonal wave heights in the western and northwestern Bay of Bengal are spread over a wide range. It is interesting to note that the scatter diagram (Fig. 6) also indicates similar feature.

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Pollution in River Par & Its Abatement

M D ZINGDE, R V SARMA & B N DESAI
Regional Centre, National Institute of Oceanography, Versova, Bombay 400 061

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Par River estuary receives about 25,000 m^3/day of effluent from a large chemical complex. The tidal effect at the present discharge point is weak and sufficient dilution water is not available except during spring tides. During monsoons, due to flushing, good water quality within the estuary is observed which, however, deteriorates after March when the river flow becomes negligible. The effluent does not mix well with sea water and flows downstream during the ebb tide. DO, BOD and *p*H show variation with the tidal stage. Flushing time computed employing tidal prism method is 1.4 tidal cycles while with fraction of fresh water method it is 4.4 days. Dye dispersion studies indicate that an appreciable fraction of the effluent would be washed to the sea during ebb tide if discharged about 3 km downstream.

River Par, originates in Satpura Mountains and runs almost in the east-west direction before joining the Arabian Sea, south of Gulf of Cambay. The width which is about 100 to 200 m in the fresh water zone changes significantly to about 1500 m near the mouth of the estuary. The river entrance is shallow due to heavy silting and is not navigable during low tides. The estuarine part extends only up to about 6 km during the postmonsoon season. Further intrusion upstream is obstructed by a weir constructed across the river (Fig. 1) to store fresh water for supply to a large chemical complex on the northern bank. The chemical complex discharges about 25,000 m^3/day of effluent into a natural drain opening in the estuarine region, just below the weir.

The present survey has been carried out to determine the feasibility of discharging the effluent into the estuarine region of the Par River and to evaluate the extent of treatment required to eliminate the existing pollution conditions.

Materials and Methods

Seven sampling stations were fixed from the mouth to the point at which the effluent is discharged (Fig. 1).The 8th station was located in the drain carrying the effluent. Monthly collections were made between June and September 1977. Samples were collected at flood and ebb tides. Unless specified, the discussion in the paper relates to the measurements carried out in early June to cover the period when the river flow was minimum.

Currents were measured periodically using Ekman-Mertz type TSK current meter at sts 2, 3 and 5 over full tidal cycles. When the depth was > 3 m surface, middle and bottom currents were measured. Surface currents were measured 1 m below the surface and bottom currents 1 m above the bottom.

Echograms were taken near every sampling station during high and low tides using Fathometer (Model DE719D). Profiles across each section were plotted after correcting for transducer length and the tide.

Salinity over complete tidal cycle was measured at all stations. Surface and bottom samples were collected when the depth was > 2 m. Salinity was determined by argentometric titration[1]. Oxygen was determined by Winkler's method[1]. Direct method[2] was employed for estimating samples having BOD < 4 mg/litre. For samples having higher BOD, unseeded dilution method was used. Seeded dilution method was used for analysing the industrial effluent. The samples were incubated for 5 days at 20 ± 1°C in a BOD incubator. Determination of *p*H was done on Philips Model PP9040 portable *p*H meter. The instrument was calibrated with standard buffers before use.

Results and Discussion

Sea water intrusion—Tides at the mouth of the estuary are mixed semidiurnal type. Tidal influence within the estuary was investigated during the spring and neap tides by installing staff gauges near sts 2, 5 and 7. They were read every 30 min over a complete tidal cycle. Fig. 2 shows instantaneous water level plotted against time. The plots give a relative rise and fall of the water level in a given tidal cycle. The depth at high tide slack during the spring tide was about 5.5 m at st 2. It was only 2.5 m at st 7. During the corresponding ebb tide, the water level at st 2 was only 0.3 m while at st 7 it had completely receded exposing the river bed. The effluent was then seen to flow through a narrow midstream channel which retained some sea water. The

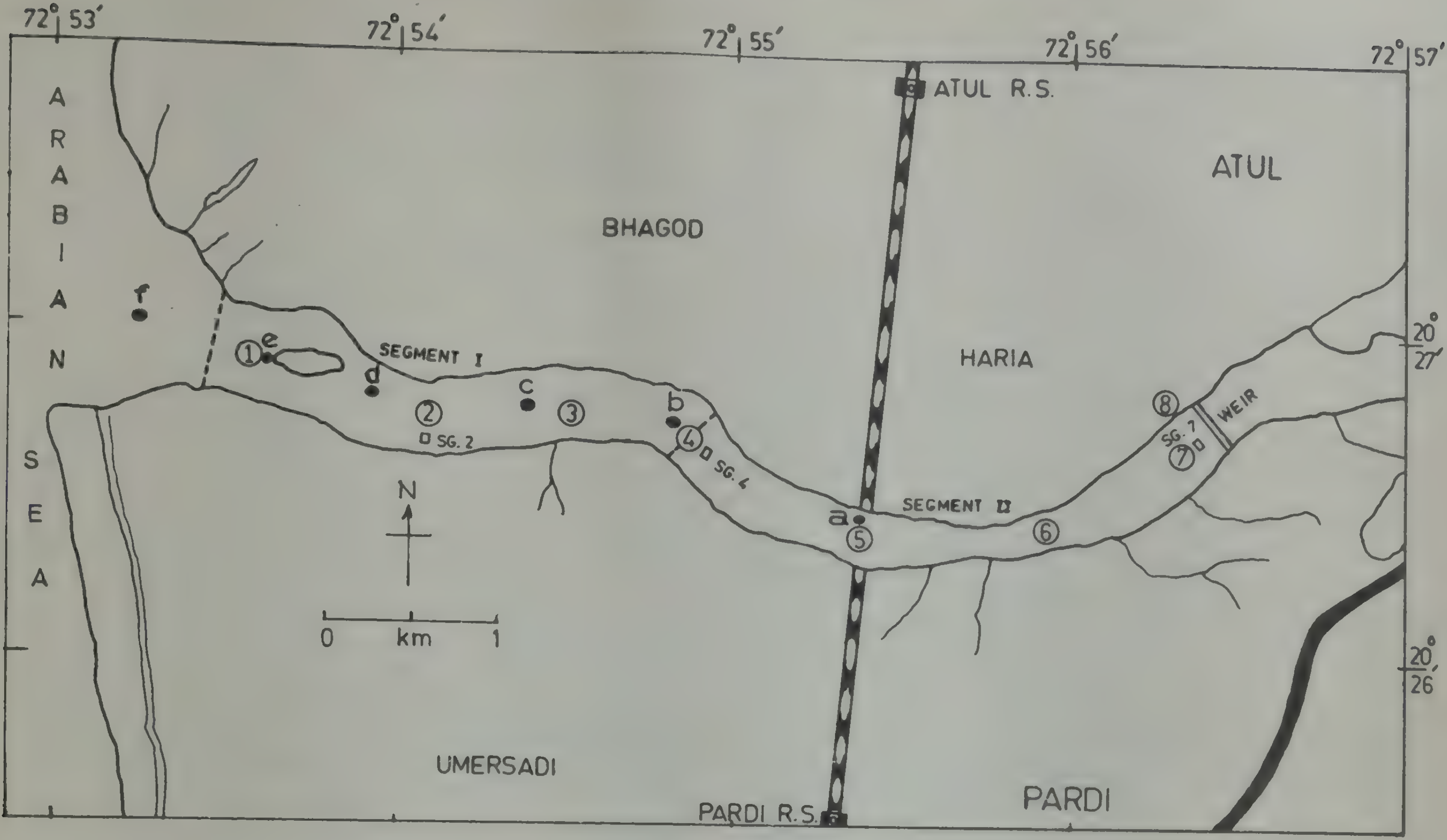

Fig. 1—Station and staff gauge locations and positions of dye-patch during ebb tide on 8.6.77 [a to f indicate position at different time (hrs) intervals: a, 0800; b, 1000; c, 1100; d, 1200; e, 1230; and f, 1300]

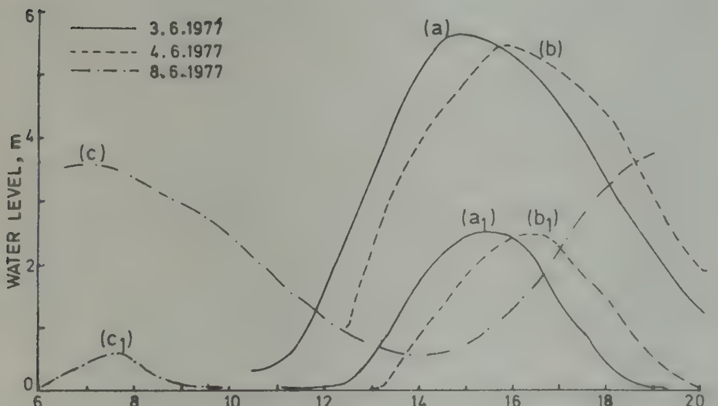

Fig. 2—Variation of water level with time at staff gauges 2 and 7 on 3rd, 4th and 8th June 1977 [a, b, c at staff gauge 2 and a_1, b_1, c_1 at staff gauge 7]

tidal periods also varied widely at sts 2 and 7. While, the flood period (from ebb slack to flood slack) at st 2 was of about 5 hr (spring) duration, it was only 2.5 hr (spring) at st 7. The variation in time at the 2 stations may occur because the river bed has a gradient with upward slope towards the east. The weir also perhaps affects the tidal period at st 7. During the neap tide, when the water available for dilution of the effluent would be minimum, the flood water remained near the discharge point for 2 hr with the maximum rise of 0.5 m as against 3.5 m at st 2. Similar measurements at st 5 indicated an appreciable tidal influence as compared to st 7 with the tidal range of 4 m on a spring tide. It is, thus, evident that during spring tides, sea water for dilution of the effluent is available for nearly 5 hr (Fig. 2) in a tidal cycle at the effluent disposal site while during neap tides not only the quantity of water is largely reduced but is available only for 3 hr in a tidal cycle. It is, therefore, apparent that the present effluent disposal site is quite unsuitable and the waste should be discharged further down at a point where sufficient dilution water is available.

Salinity—High salinity (35.3 to 20.9$^{o}/_{oo}$) observed during the premonsoon period is an indication of low fresh water discharge. During August, even at st 2, the salinity was as low as 4.34$^{o}/_{oo}$ at the high tide indicating the influence of monsoons. The combined drainage area for the Par River and its tributaries is about 1225 sq km and receives average precipitation of about 120-180 cm during July to September. The river, therefore, experiences large fresh water discharge and remains flooded during this period. However, the river goes almost dry after March.

Flood and ebb salinities for different stations have been plotted in Fig. 3. During the flood tide, the salinity decreased from over 32$^{o}/_{oo}$ at st 1 to $<$32$^{o}/_{oo}$ at st 5 and then decreased to 21.29$^{o}/_{oo}$ at st 7. During ebb tide, the salinity at st 6 decreased to 20.92$^{o}/_{oo}$ as against 31$^{o}/_{oo}$ during flood tide. In the absence of any river discharge, in the premonsoon period, the decrease in salinity could be either due to the dilution of seawater with the effluent or due to incomplete mixing and perhaps some piling up of the effluent. The accumulated effluent flows

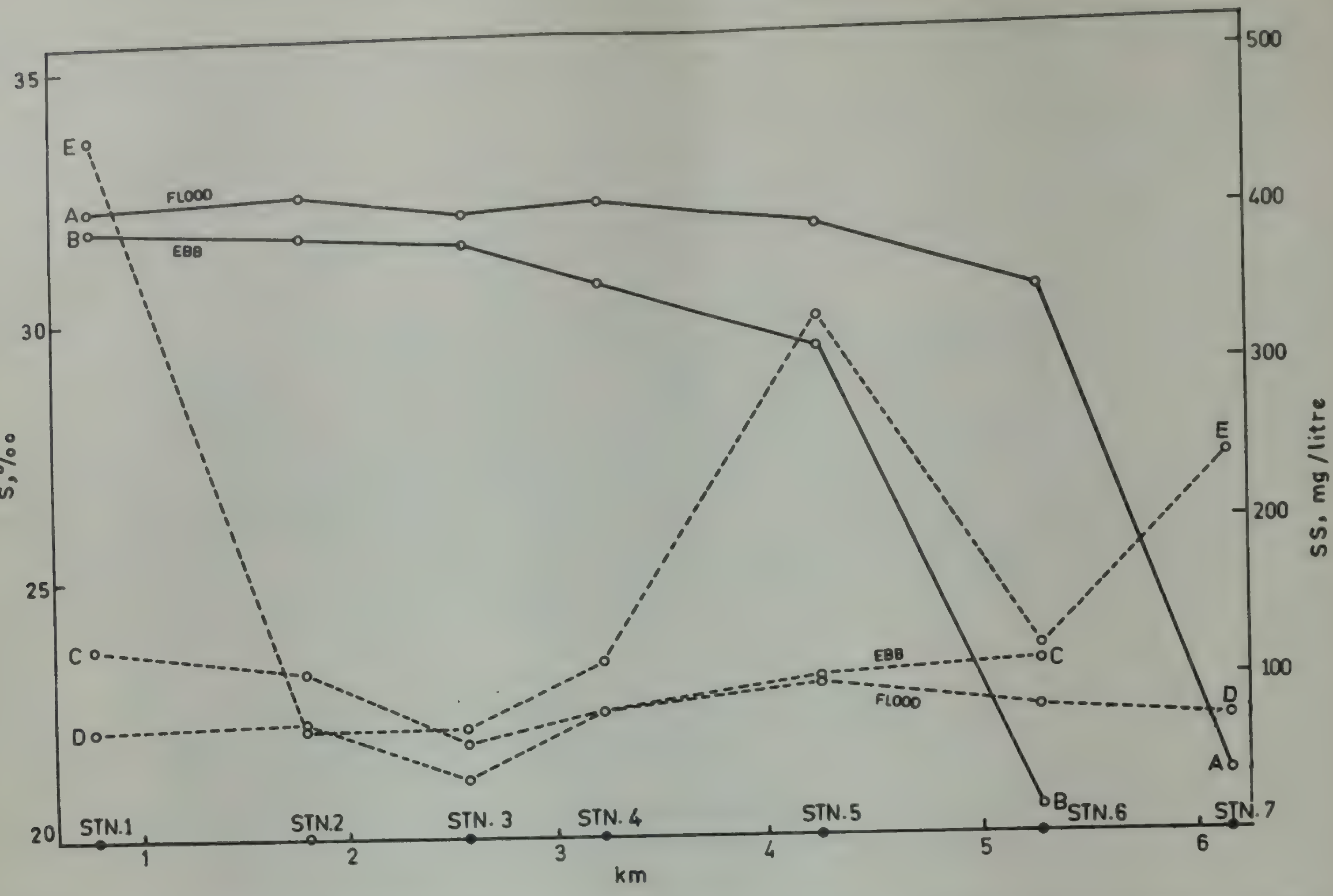

Fig. 3—Variation of salinity (—) and suspended solids (-----) at different stations [A, C during flood tide and B, D during ebb tide on 7.6.77. E during flood tide on 29.6.77]

downstream with ebbing water without complete mixing which decreases the salinity at the downstream stations as ebb tide progresses. The average volume of sea water flowing across st 4 is of the order of 8×10^5 m^3 during the high tide. The maximum quantity of effluent discharged during that period is 12,500 m^3 which is insufficient to reduce the salinity from 34.15 to $30.45^{\circ}/_{oo}$. It, therefore, appears that the effluent does not mix completely with the sea water.

Flow characteristics—Currents during early June were tide induced as the river flow had practically stopped. Evidently the current speed and direction were entirely due to tidal sweep. Instantaneous current speed against time is given in Fig. 4. The peak flood and ebb currents were fairly strong. Maximum current of 155 cm/sec was observed at st 2 during the spring flood and a maximum ebb current of about 120 cm/sec was, observed during the neap tide. The peak flood and ebb speeds were obtained about 3 hr after the commencement of the tide (Fig. 4). The peak current preceded the corresponding high and low water by about 3 hr. The current was maximum at the surface and decreased marginally at the bottom. The observed speeds indicated swift water movements in the estuary which would facilitate better mixing if the effluent is properly discharged at an appropriate location.

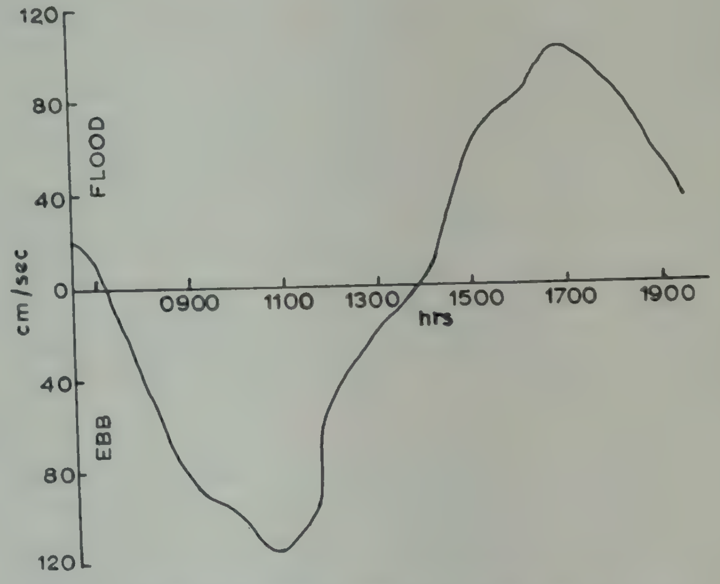

Fig. 4—Variation of current speed with time on 7.6.77 at st 2

Flushing time was calculated applying tidal prism method[3]. Cross-sectional profiles were utilised to calculate the average low tide volume and the average intertidal volume (Fig. 5). Since there was no river flow in early June, the effluent amounting to 25,000 m^3 per day was considered as the fresh water discharge. The average tidal prism was estimated to be 2807×10^3 m^3 and the average low tide volume 1188×10^3 m^3. The flushing time is then calculated to be 1.4 tidal cycles.

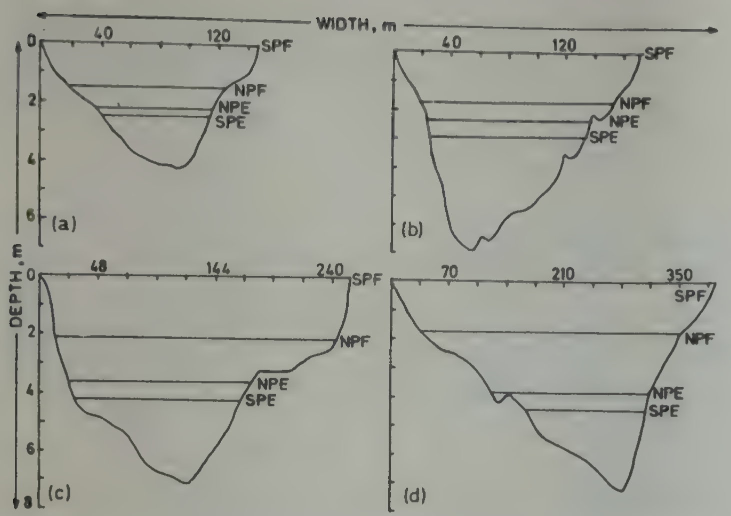

Fig. 5—Cross-sectional profiles [(a)-st 6, (b)-st 5, (c)-st 4, and (d)-st 2. SP, spring; NP, neap; F, flood; E, ebb]

The fraction of well mixed water that would be removed from the estuary after one tidal cycle under these conditions would be around 70%. After an infinite number of tidal cycles, under a continuous flow of pollutants into the estuary, the load remaining could be expressed as $L = Y/(1-Y)$, where Y is the fraction remaining after 1 tidal cycle and L is the multiple of load introduced per tidal cycle. In this case L is approximately 0.5. It, therefore, appears that a large fraction of the effluent discharged in the estuary will be removed provided the effluent mixes well with the sea water.

An attempt was also made to calculate the flushing time by applying fraction of fresh water method[3,4]. The estuary was divided into 2 segments (Fig. 1)—segment I between st 1 and 4, and segment II between st 4 and the weir. The average volumes of segments were calculated from the knowledge of cross-sectional areas (Fig. 5), high and low tide levels and distance between the cross-sections. The average volumes of segments I and II were 1302×10^3 and 696.8×10^3 m^3 respectively. To obtain average chloride concentration, variations in the chloride content of surface and bottom water were measured hourly over complete tidal cycles at the water quality stations and then averaged for each segment. The values obtained were 18.6 and 17.2‰ for segment I and segment II respectively. The chloride content of the bay water was obtained by collecting the samples about 1 km away from the mouth of the estuary. The average of 10 determinations was 19‰. The industrial effluent was the only source of fresh water with an average chloride content of 0.85‰. Using these values, flushing time was found to be 1.2 days for segment I and 4.4 days for segment (I + II). A comparison of these results with the value obtained by tidal prism method indicates that the value obtained by the tidal prism method is much lower.

Dye dispersion studies—Dilution studies to evaluate the extent of mixing using fluorescein dye were conducted to coincide with the neap tide. About 20 g of dye was dispersed in 20 l of water-alcohol mixture and released. The dye movement was closely followed and samples were periodically collected to calculate dilution factor. The dye was replenished whenever necessary. Initially, the dye was released at the present effluent discharge location during the flood slack. The effluent, however, strongly influenced the dye and the patch quickly disappeared. The studies were, therefore, shifted to st 5. The patch took 5 hr to reach the mouth. The positions of the dye patch are marked in Fig. 1. The speed of the dye patch increased from 17 to 33 cm/sec from st 5 to the mouth. The ebb current speed at st 4 on the same day was about 50 cm/sec. The dye patch moved with an average speed of about 26 cm/sec. The decrease in the movement of dye patch was perhaps due to increased diffusion and dispersion as the patch moved further. During the dye studies the average wind velocity recorded was about 15 km/hr predominantly in the southwest direction. Evidently, the wind was blowing against the flow of ebbing water and the dye patch being on the surface, its movement was affected more. The dye studies also support the conclusion that a large fraction of the effluent would be carried to the sea during the ebb tide. The absorbance of the colour was measured on a spectrophotometer at 550 nm. On the basis of the results obtained, it has been tentatively concluded that the dilution at position (b) was 1:50 and at position (f) it was 1:4000. This indicates that a fair amount of dilution can occur if the effluent is released properly at a suitable location.

Water quality—The incomplete mixing of the effluent with sea water influenced the water quality at downstream stations which varied depending on the stage of the tide. Physicochemical analysis of the effluent at the discharge point is given in Table 1. Although the effluent with an average suspended load of 200 ppm roughly added 5 tonnes of suspended load/day, its contribution to the estuary water would be negligible considering the average volume of the Par River and high natural suspended load of the sea water

Table 1—Analytical Data for Effluent Collected at Station 8

Conc. (ppm)	Maximum	Minimum
Suspended solids	300	102
Total dissolved solids*	10.2	3.6
Chlorides†	1.2	0.32
*p*H	3.2	2
DO	0.3	0
BOD	323	100
Total phosphorus	3.1	1.6
Total nitrogen	4.6	0.9
Sulphates	1.5	0.5
Phenolics	8.3	1
Oil and grease	65	22

Concentration expressed in *ppb and †ppt

(32 to 125 ppm). The variation of suspended load at different stations is given in Fig. 3.

The effluent had *p*H of <3 and 6.5 at sts 7 and 4 respectively at the ebb slack. As marine fauna is highly sensitive to acid *p*H the effluent should be properly neutralized before discharge.

A good fraction of the BOD load of the effluent (Table 1) would be washed to the sea during the ebb tide which will influence dissolved oxygen levels in the estuary. DO markedly decreased from the mouth to the weir and at any given location it varied with the stage of the tide. Thus the high tide value at st 5 which was 6.2 mg/litre, decreased to 1.4 mg/litre at ebb slack. Likewise at st 2, about 5 km downstream, the value at the high tide was 6.8 mg/litre which decreased to 2.5 mg/litre during the low tide. DO content of the region between sts 5 and 7 was normally between 2 to 3.5 mg/litre even during the neap flood tide. The tidal influence is weak in this region and hence this region is significantly affected by the effluent. Considering the tidal inflow during the flood tide, it is unlikely that any decrease in DO to 2.5 mg/litre at st 2 is due to oxygen deficiency. This decrease appears to be due to the effluent collected during the high tide flowing downstream.

Acknowledgement

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Physicochemical Studies on Coastal Pollution Off Bombay

M D ZINGDE, S K TRIVEDI & B N DESAI
Regional Centre, National Institute of Oceanography, Versova, Bombay 400061

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Variations of salinity, dissolved oxygen (DO) and biochemical oxygen demand (BOD) in the creeks, bays and coastal region around Bombay were studied. Currents varied depending on the tide and their direction in creeks and streams was dominated by the physical features of the channel. Currents did not vary appreciably from the surface to bottom. Salinity varied widely from <5‰ during August to >34‰ after March. Generally, the monsoon period was characterised by well marked vertical salinity gradient except in the coastal region, which disappeared at most of the stations during the postmonsoon period. Coastal water was vertically homogeneous throughout the year while some lateral salinity gradient was observed during August. DO profiles were similar at most stations. In general, higher DO observed in August sharply decreased during September and then gradually increased to maximum in February, followed by a gradual decrease till May. This trend appears to be due to the combined effect of BOD, temperature and photosynthetic activity. Abnormally low DO and high BOD were observed at Upper Thana, Mahim Bay and Versova Creek due to the influence of waste water discharged at these locations. Mahim Bay was worst affected with DO levels sometimes falling to <1 mg/litre.

The combined waste water discharge from domestic and industrial establishments in and around Bombay (lat. 18°55′ N, long. 72°49′ E) imposes strain on the receiving marine environment and deteriorates the water quality. Preliminary report[1] indicates that the quality of water of the harbour region has deteriorated. Extensive survey has been carried out to determine the state of pollution of the receiving water mass and to locate suitable sites for discharge of treated waste water which can easily be diluted and dispersed. This paper presents data on variation of salinity, dissolved oxygen (DO), and biochemical oxygen demand (BOD) of the marine environment around Bombay.

Materials and Methods

Water quality at several stations (Fig. 1) around Bombay was monitored for 16 months from May 1976. The stations were grouped together as given below, to present a general picture of the region studied.

Thana Creek stations—Data on various parameters from sts 1 to 9 were monitored during ebb-flood and flood-ebb cycles every month at spring and neap tides. Normally, samples from each station were collected at every 2 hr interval. As no significant differences in the values from ebb to flood and flood to ebb cycles were observed, the values obtained during 1 month for a particular location were averaged. In addition samples were also analysed from tributaries (I to VIII, Fig. 1) which join Thana Creek.

Stream monitoring stations—Sts 10 to 17 were monitored over a complete tidal cycle once a month. Samples were collected at hourly intervals and the values averaged.

Coastal stations—Sts 18 to 20 including 18a were monitored once a month over complete tidal cycle.

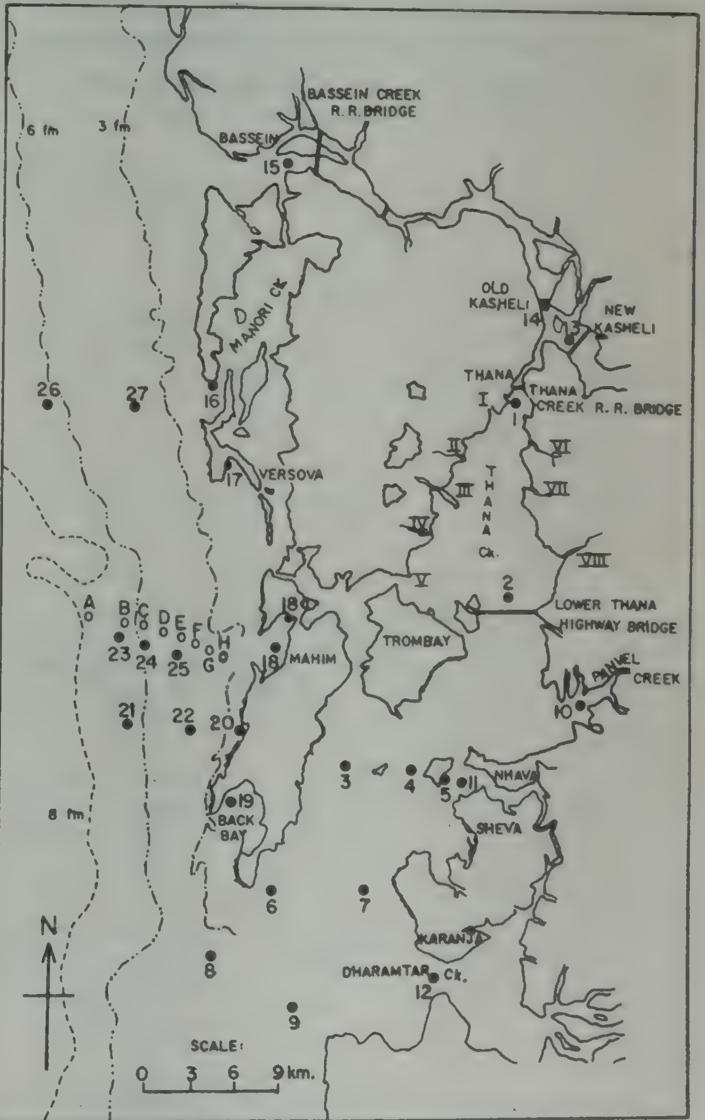

Fig. 1—Sampling stations

Other stations (21 to 27) were in the coastal region on 3 transects and were monitored once in a month. In addition sts A to H were monitored once in a month during August, September and October.

Samples were collected from surface, middle and bottom when the depth was > 5 m and from surface and bottom when the depth was < 5 m. Only surface samples were collected when the depth was < 1.5 m.

Oxygen was determined by Winkler's method[2]. For the determination of BOD[3], direct method was employed for samples having BOD < 4 mg/litre and for samples having higher BOD, unseeded dilution method was employed. The samples were incubated for 5 days at 20 ± 1°C in a BOD incubator. Salinity was determined by argentometric titration method.

Currents were measured either by continuous recording General Oceanics current meter or by Gurley impeller type current meter. Tidal elevations were measured by installing staff gauges.

Results and Discussion

Thana Creek stations—Thana Creek (Fig. 1) receives about 25 mld of waste water discharges from about 30 major industrial establishments.

Tides and currents: Tidal variations in Thana Creek are semi-diurnal with an appreciable diurnal element. A tidal exchange flow between Thana Creek and Ulhas River/Bassein Creek is possible since the tidal effect is felt earlier at st 1 than st 13. As a result, during flood tide, the water may flow from Thana Creek to Bassein Creek depending on the relative levels of high water in the 2 creeks. During the ebb tide, however, the water receeds earlier at st 1 and the flow gets reversed. Hence, the possibility of effluents discharged in the Thana Creek entering the Bassein Creek and vice versa, cannot be ruled out.

Currents within Thana Creek are almost entirely due to the tidal ebb and flood flows and the velocity varies depending on the stage of the tide during the dry season. Between sts 8 and 9, maximum ebb velocity of 115 cm/sec was recorded during the spring ebb tide and 70 cm/sec during the spring flood tide. Higher velocities of the order of 150 cm/sec were observed in some instances. The currents maintained almost the same direction from the surface to bottom and their velocities decreased only slightly. The velocity, however, decreased appreciably from the mouth of the creek towards st 1, where the velocity rarely exceeded 25 cm/sec and the maximum velocity observed at st 2 was 50 cm/sec during the spring ebb tide. The monsoon fresh water flow influenced the current velocity.

Salinity: Salinity of sts 1 to 9 varied from 7.19 to 38.16$^{o}/_{oo}$ (Fig. 2). The minima attained in August may be due to the surface run off and the fresh water

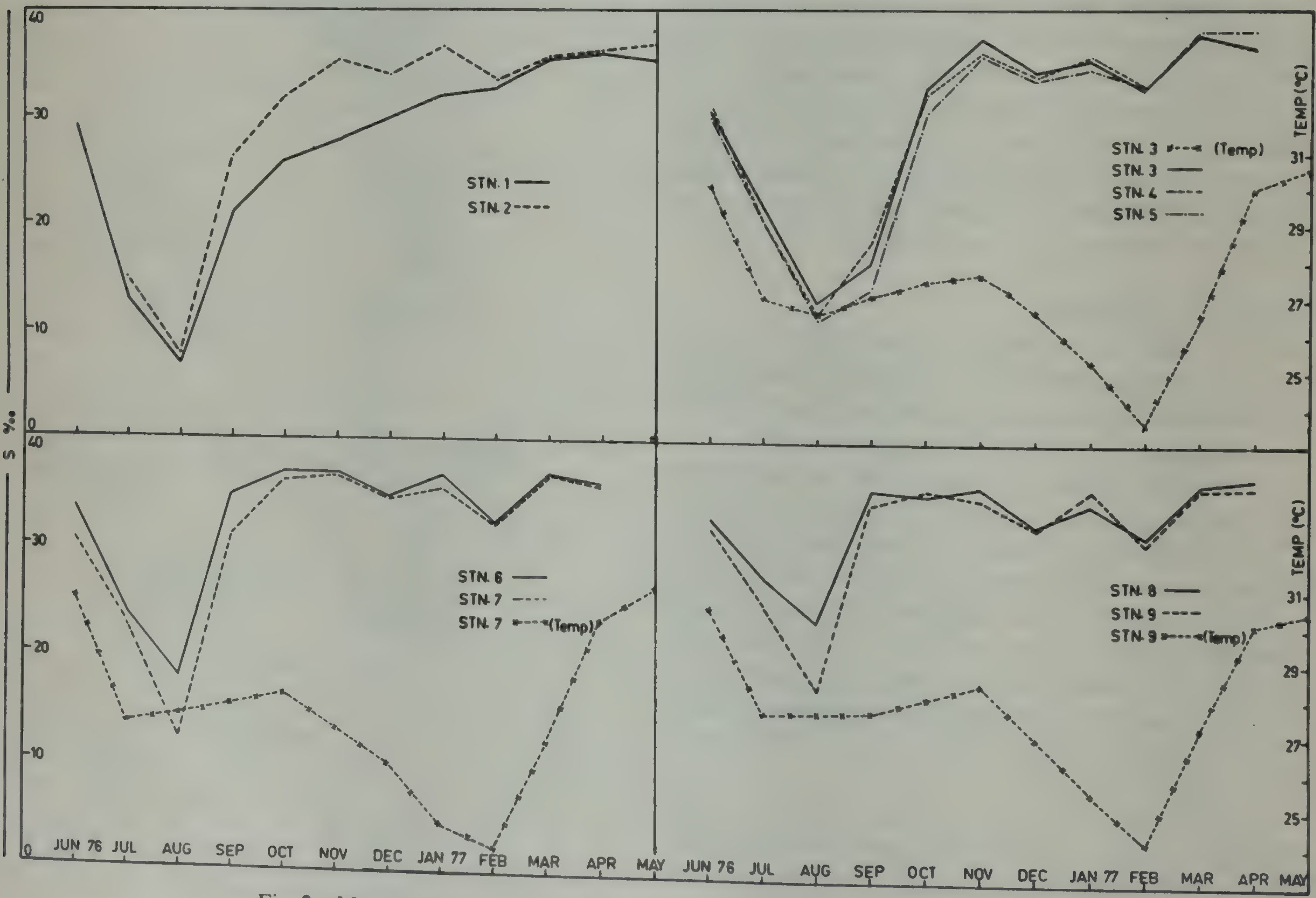

Fig. 2—Monthly variation of salinity and temperature at Thana Creek stations

discharge from the Ulhas River and other creeks. Although the peak salinity observed was 38.16$^{o}/_{oo}$, in some isolated instances, salinity as high as 40.32$^{o}/_{oo}$ was measured during March-May along certain shallow regions lying close to the salt pans, mud flats and mangroves. Comparatively high salinity (37-38$^{o}/_{oo}$) observed during March-April may result from some local factors as mentioned above, since the sea water outside the creek had a salinity around 36.5$^{o}/_{oo}$ during this period. Low salinity was observed during August with a definite salinity gradient from 7.19$^{o}/_{oo}$ (av.) at st 1 to 23.82$^{o}/_{oo}$ (av.) at st 8 (Table 1). Except at st 1, the salinity increased during October and attained a range of 32-36$^{o}/_{oo}$. There was no significant vertical salinity gradient except at st 1, during March (Table 1). Surface and bottom salinities differed markedly at st 1 from August till December. The overall salinity at st 1 was lower than that observed at the downstream stations in any month. The low salinity can be due to the discharge of low saline water from the Ulhas River which is considerably reduced after January. The monsoon period was characterised by a well marked vertical salinity gradient (Table 1). With the influx of fresh water, the difference between surface and bottom layer was appreciable. Diurnal variations at sts 1 and 2 during August, indicated appreciable increase in salinity with the flood tide followed by a decrease with the ebb tide. Although there was great influx of fresh water, during the flood tide, there was intrusion of saline water along the bottom. The effect of this was felt up to st 1. Bottom salinity, however, was lower at this location as compared to st 2 indicating an appreciable mixing of both saline and fresh water.

Table 1—Salinity and DO at Some Stations during August and March

Station	Salinity ($^{o}/_{oo}$)			Oxygen (mg/litre)		
	S	M	B	S	M	B
			August			
1	0.8	8.86	11.9	5.4	4.4	4
3	9.65	12.65	16.88	7.6	7.2	3.7
5	5.72	10.14	18.08	6.9	6	3.8
6	11.19	18.04	24.76	7	6	5
7	9.68	13.88	17.94	7.8	6.9	4.2
8	17.34	22.39	31.73	6.9	6.3	5.6
9	14.2	16.97	22.44	7.8	6.4	4.5
10	4.05	8.18	13.84	6.3	5.7	5.5
13	1.22	1.22	1.91	4.1	4.2	4
14	0.68	1.53	1.76	4.1	4	4.1
16	16.82	16.86	18.44	7.2	—	5.8
17	15.39	16.95	17.87	7.2	6.1	5.6
18	6.28	—	12.27	3	—	2.6
18a	2.8	—	—	0.5	—	—
19	27.5	27.92	34.51	8	2.2	2
22	29.5	30.21	30.82	6.6	6.3	5.2
			March			
1	35.23	—	35.68	4.6	4	3.5
3	37.85	—	38.08	6.5	6.3	5.1
5	36.8	—	38.12	6.8	6.3	5.6
6	37.16	36.67	36.64	6.7	5.8	6
7	36.23	37.06	37	6.2	5.9	5.5
8	36.35	—	36.35	6.8	6.8	6
13	28.06	28.86	30.01	4.3	3.2	4
14	29.8	30.06	30.24	3.6	—	4
16	34.52	—	35.23	6.9	—	7.2
17	27.07	34.91	35.28	3	4.6	5.2
18	32.63	—	35.48	1.3	—	2.6
18a	32.9	—	—	0.5	—	—
19	35.14	35.5	36.67	6.5	6.2	6.1
22	36.29	36.15	36.82	7.4	6.9	6.8

S = surface; M = middle; B = bottom

Dissolved oxygen: DO content at sts 3 to 9 was more or less similar (Fig. 3). DO of 6 mg/litre recorded during August decreased to about 4 mg/litre during September and then gradually increased to attain a peak (8.5 mg/litre) during February. This was followed by a gradual decrease till May. This is perhaps due to the combined effect of temperature, photosynthetic activity and biochemical oxidation of the waste entering the marine environment. Although average values normally varied in the range of 3.7 to 9.2 mg/litre abnormal values were occasionally observed. Values < 2 mg/litre were observed at sts 3 and 4 in some collections during September. Highest DO of 10.1 mg/litre was observed at st 9 at the surface during February. DO distribution in the vertical water column was fairly uniform during the post monsoon period showing marginal decrease with depth. This supports the earlier conclusion that the water in the creek is well mixed in the postmonsoon season. DO decreased appreciably from surface to bottom during August. The differences in DO observed between surface and bottom layer (Table 1) could be due to the large influx of fresh water of high oxygen content (Fig. 2) which formed the major component of the surface since vertical mixing was partially restricted by the salinity gradient (Table 1). Low DO during September could be mainly because of the additional oxygen demand by the sinking suspended load brought in by the run off. Although the average surface and bottom values were 4.3 and 3.9 mg/litre respectively, lower values of 2-3 mg/litre were occasionally observed, specially at st 6 for the subsurface water. This may be due to biochemical oxidation of organic waste transported by run off. At the same time the supply of oxygen rich fresh water decreased substantially. Samples collected during August and May starting from the mouth of the creek to the Thana Railway Bridge (TRB) showed decrease in DO along the length of the creek (Fig. 4) from the mouth up to the bridge. The decrease in the creek region was more pronounced in May indicating the fall in water quality as a result of

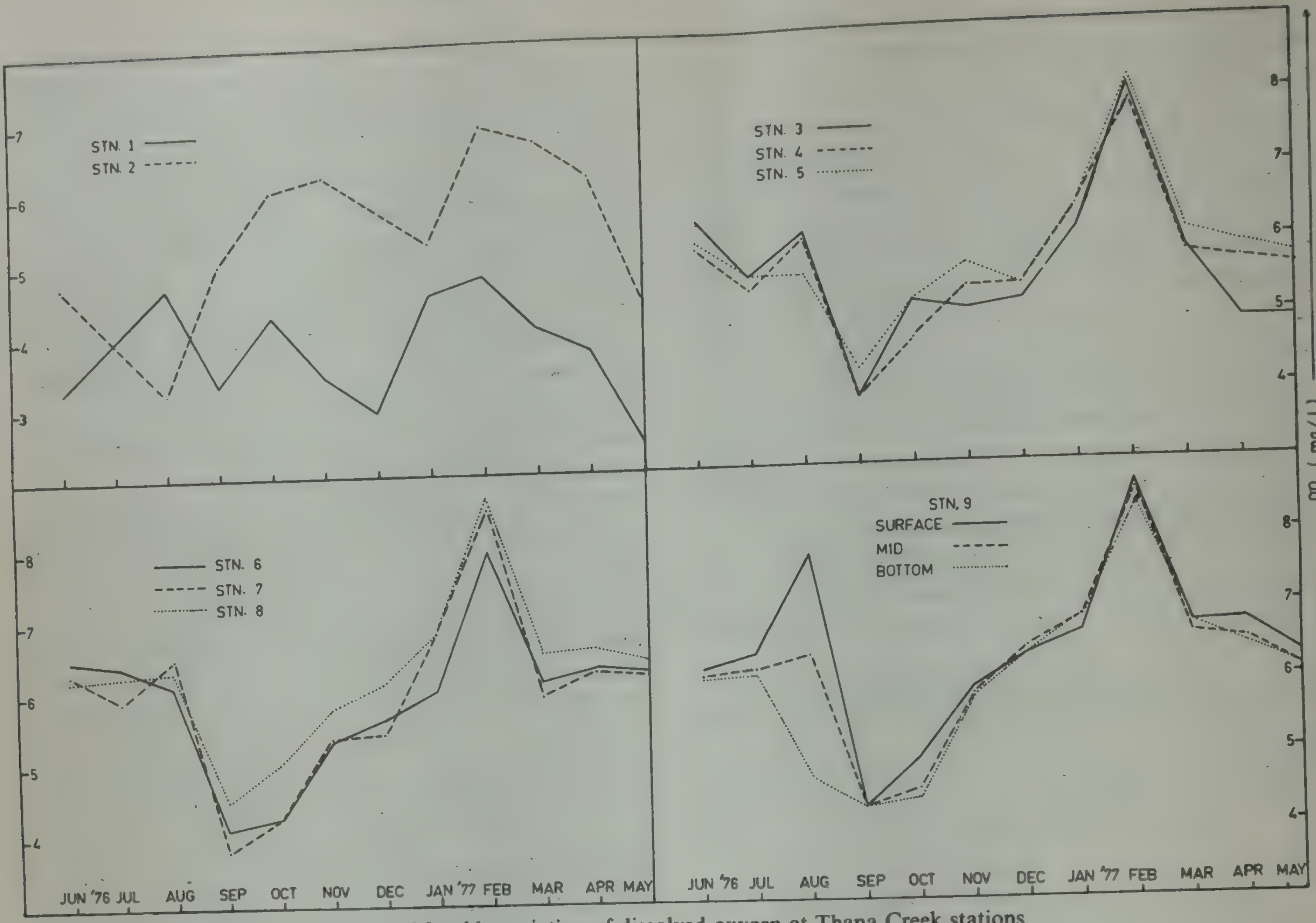

Fig. 3—Monthly variation of dissolved oxygen at Thana Creek stations

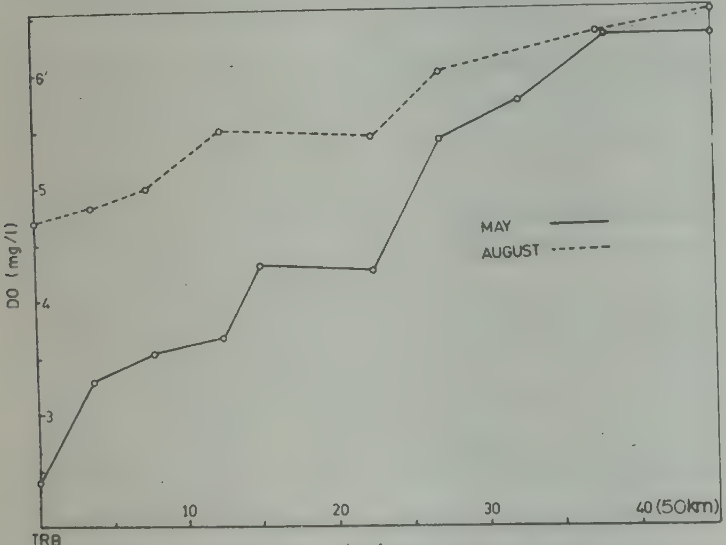

Fig. 4—Variation of dissolved oxygen in Thana Creek/Bombay Harbour during August and May

effluent discharge. Comparison of DO profiles at sts 1 and 2 (Fig. 3) with those at other stations reveals the inconsistency in DO levels at sts 1 and 2.

Sampling during flood tide was also done inside the small tributaries joining the Thana Creek (sts I to VIII; Fig. 1), weekly during September. DO values (Table 2) varied from 6.7 to 0.9 mg/litre. Some of these tributaries receive industrial and domestic waste water discharges and hence large variation in DO.

Table 2—DO and BOD (mg/litre) for Tributaries Joining Thana Creek

Date	Parameter	Tributaries							
		I	II	III	IV	V	VI	VII	VIII
01.9.77	DO	5.6	5.9	4.7	4.4	6.4	5.9	4.6	3.8
	BOD	14.5	3.3	3.8	14	3.4	2.7	3.3	1.2
09.9.77	DO	3,8	4.4	5.6	0.9	5.6	6.7	3.2	6,1
	BOD	13.2	2.3	—	—	2.1	3	—	4.1
14.9.77	DO	5	4.7	5.3	—	6.1	—	—	—
	BOD	2.2	13	15	—	4.5	—	—	—
22.9.77	DO	1.1	3.9	1.5	3.5	—	3.4	1	3.6
	BOD	—	—	—	—	—	—	—	3.6
29.9.77	DO	3.7	3.7	4.7	2.3	5.3	3.4	—	—
	BOD	1.6	12.3	13.3	11.2	4.8	2	—	—

No definite pattern in the variation of BOD within the creek was observed. In general, BOD values exceeding 2 mg/litre were observed (Table 3) during August and September which were associated with the high organic matter received through the run off. Values > 5 mg/litre were often observed at st 1 in April-May which may be due to the sewage effluents. Sometimes during the ebb tide, values of the order of 8-10 mg/litre were observed at this station during March to May which may also be due to sewage discharge having high BOD.

Stream monitoring stations—Panvel, Nhava Sheva and Dharamtar Creek (Fig. 1) which open in the eastern region of the Thana Creek/Bombay Harbour are relatively clean. Bassein Creek on the other hand receives waste water (35 mld) discharged in the Ulhas River. Unlike Manori Creek which is relatively free of pollution, Versova Creek receives about 80 mld of sewage waste from the Versova treatment plant.

Tides and currents: The flood tide effects are first felt at st 12 (av. high tide lead 30 min and av. low tide lead 1 hr) which receives high water earlier to Apollo Bundar. At st 10, the average high tide lag was 52 min and the low tide lag was 30 min.

Table 3—BOD (mg/litre) at Some Stations from August 1976 to May 1977

Station	1976					1977				
	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1	2.2	6.3	2.7	—	3.4	—	1.3	3	5.8	5.8
3	2.5	5.6	1.5	0.8	1	0.8	—	2.1	1.5	2.2
5	2.8	2.8	1.6	1	0.6	1	1.4	3.1	1.7	2.3
7	2.6	—	0.6	0.7	0.9	1.9	1.6	3.8	2.3	1.4
9	2.1	3.2	—	—	2.4	0.9	2.6	—	1.6	1.4
10	2.7	2	0.8	—	—	2	2.9	0.3	1.6	2.8
12	0.8	—	2.5	3.9	—	0.8	1.2	3.6	4.5	—
17	2	4.3	—	2.3	1.5	1.1	2.4	3.7	4	5.1
18	5.3	6.8	10.3	8.4	8.6	9.2	6	12.6	20.8	28.6

Current direction and speed at these stations were mainly influenced by the tidal condition and were dominated by physical feature of the stream channel. Comparison between spring and neap tide conditions indicated faster currents during the spring tide and the ebb velocity was generally greater than flood velocity. The ebb velocity increased substantially during August, and on several occasions, attained a value >130 cm/sec specially at sts 10 and 14 due to the fresh water discharge. The current did not vary appreciably in speed and direction from surface to bottom.

Salinity: Salinity varied widely from 1.32$^{\circ}/_{oo}$ during August to 30.03$^{\circ}/_{oo}$ during March (Table 1) at st 14. Except at st 14, the salinity of 18-30$^{\circ}/_{oo}$ during September increased to 30-35$^{\circ}/_{oo}$ after October (Fig. 5). At st 14 salinity was lower in September (1-3$^{\circ}/_{oo}$) and increased to 10-13$^{\circ}/_{oo}$ during October. It is evident from Fig. 5 that the average salinity observed at st 14 was lower than the other stream monitoring stations during all the months and the maximum salinity of 30.24$^{\circ}/_{oo}$ observed during March indicates the supply of fresh water through Ulhas River throughout the year. As in the Thana Creek region, high salinity in the range 38 to 39$^{\circ}/_{oo}$ was observed in isolated instances at sts 10 to 12, 16 and 17 during March-May. Variation in salinity from surface to bottom was not appreciable (<1$^{\circ}/_{oo}$) during October to June, except at sts 14, 15 and 17, indicating good mixing. Slight salinity gradient (2-3.5$^{\circ}/_{oo}$) observed at sts 14 and 15 during October to

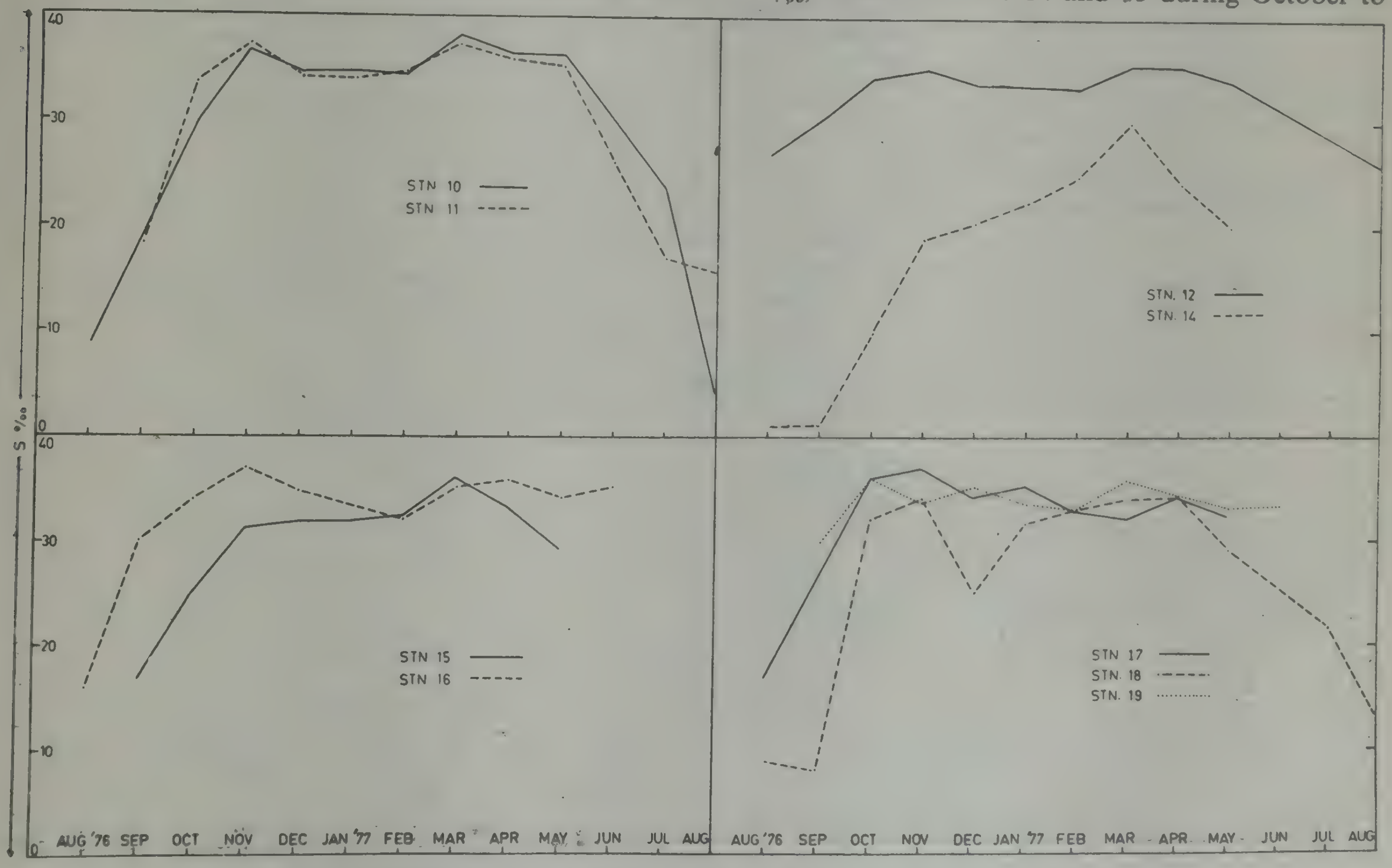

Fig. 5—Monthly variation of salinity at some stream monitoring and coastal stations

February was due to the fresh water discharge. Measurements carried out during March at st 17 showed salinity gradient from surface to bottom (Table 1). No such difference was observed at other stream monitoring stations and the gradient at st 17 may be ascribed to some local factors. It is possible that during March, Versova sewage treatment plant might have released effluent which formed some component of surface water. This was supported by DO levels (Table 1). Low DO of surface water compared to bottom layer indicates the presence of sewage effluents in the surface layer. Salinity in the vertical water column at all stations except sts 13 and 14 varied from surface to bottom in August and was due to the incomplete mixing of the fresh water with the underlying saline water. Diurnal observations conducted at sts 13 and 14 during August showed that the variation in the salinity with the change in tide was not appreciable. With the decrease of fresh water, intrusion of saline water was observed and salinity increased in the postmonsoon season.

Dissolved oxygen: DO content of Panvel, Nhava Sheva and Dharamtar Creek which join Thana Creek, varied from 4.9 to 9.4 mg/litre. The creeks had a better water quality and DO levels never fell below 4.6 mg/litre unlike at some Thana Creek stations. High DO levels during January-February were perhaps associated with lower temperature and higher photosynthetic activity. DO distribution in the vertical water column was fairly uniform in the postmonsoon period and the difference was less in August as compared to that of Thana Creek stations.

DO profiles at sts 15 and 16 followed the general pattern observed at the Thana Creek stations. However, there was no appreciable vertical gradient even during the monsoons. DO levels at sts 13 and 14 were lower than at 15 specially during the nonmonsoon period (Fig. 6) reflecting the effect of effluents discharged in the Ulhas River. DO at st 17 was comparatively lower and attributable to the sewage discharge from the nearby sewage treatment plant.

Coastal stations—Coastal region survey extended from the Colaba Point in the south to the Bassein Creek in the north and up to a distance of about 12 km from the shore line. The continental shelf being wide, the depth at 12 km line was only about 17 m below the mean sea level. St 22 was most extensively studied among the coastal stations since that area has been considered for submarine disposal of waste from the city.

Currents: During November to February, maximum current velocity of 60 cm/sec (av. 45 cm/sec) and 45 cm/sec (av. 35 cm/sec) was recorded respectively for ebb and flood tide at st 22. During slack period, the

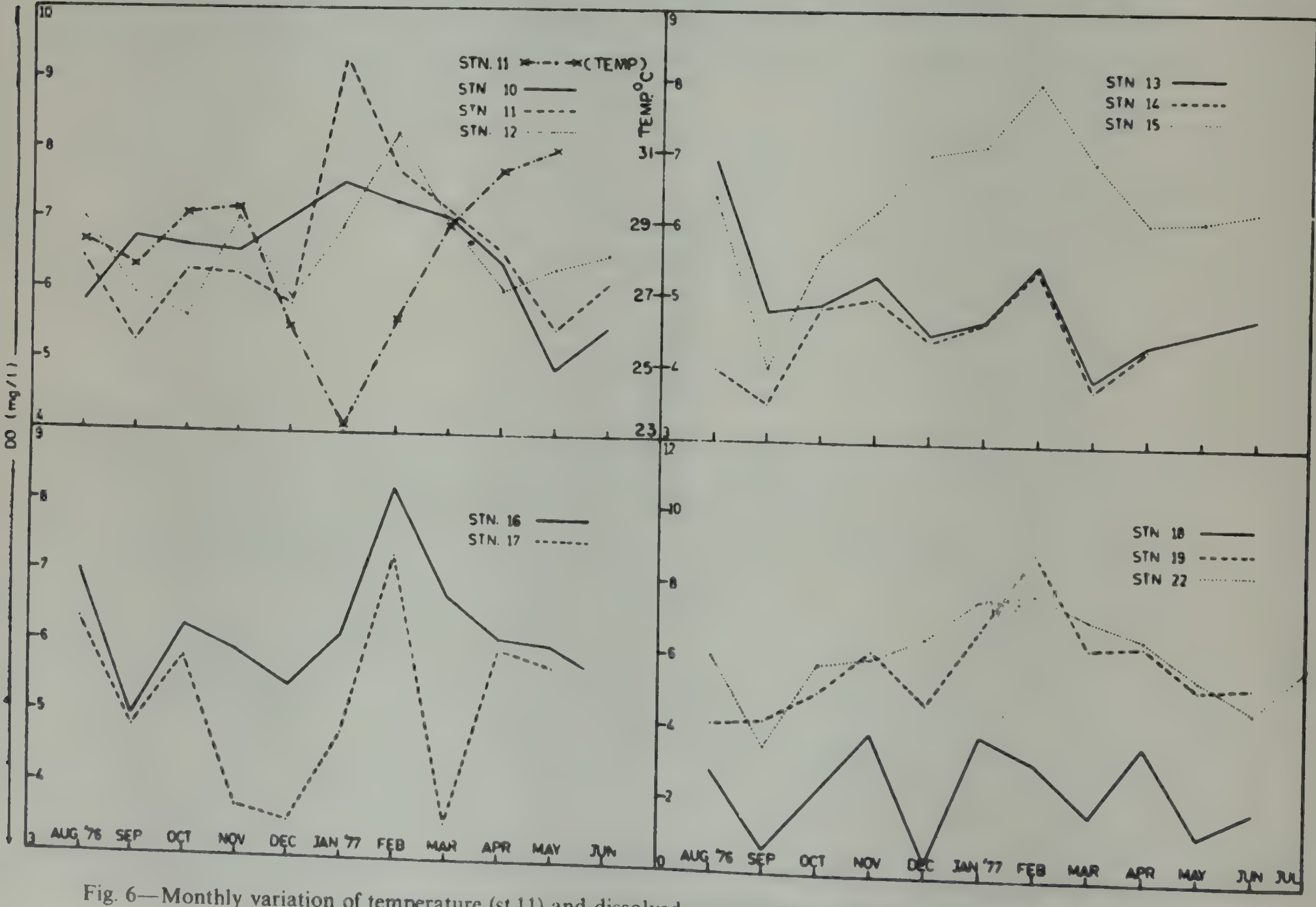

Fig. 6—Monthly variation of temperature (st 11) and dissolved oxygen at some stream monitoring and coastal stations

velocity was only 0-5 cm/sec. The currents maintained a similar direction from the surface to bottom and the velocity decreased only marginally. During the southwest monsoons the current velocity increased appreciably and often exceeded 125 cm/sec during the flood tide at st 22. The currents in general tend to move northeast during the flood tide and southwest during the ebb tide indicating a strong tidal influence on the coastal circulation. Sts 18 to 20 being in the bays the flood current velocity was appreciably smaller but the ebb velocity was almost similar to that observed at st 22.

Salinity: Salinity ranged from 29 to $33.5^{o}/_{oo}$ during monsoon period. Unlike in the Thana Creek stations there was very small vertical salinity gradient indicating good mixing of fresh water brought in by the creeks and run off. There was, however, appreciable lateral salinity gradient from the shore to the farthest stations which disappeared after September and the water was well mixed during the postmonsoon period laterally as well as vertically. The salinity of the bay water varied depending on the tide in the monsoon season with gradual increase during the flood and decrease during ebb. There was appreciable salinity gradient. During August, the average surface and bottom salinities at st 18 respectively were 6.28 and $12.27^{o}/_{oo}$. The salinity gradient was sometimes observed at st 18 even during the postmonsoon season. The average surface and bottom salinities were 32.63 and $35.48^{o}/_{oo}$ respectively during November at this station which were due to local discharges in the bay.

Dissolved oxygen: The average DO levels show little variation throughout the coastal area during a particular month (Table 1). Also, there was an absence of vertical gradient in the DO levels except during September and October. In September-October, the surface water had DO of 6.4 mg/litre while the bottom layer had only 2.9 mg/litre which could be due to the additional oxygen demand of settled suspended load brought to the coastal region during the monsoon period. Generally, variation of DO levels at st 22 was similar to that of the Thana Creek stations (Figs 3 and 6).

Table 4—DO (mg/litre) at Some Stations during August, September and October

Station	August		September		October	
	S	B	S	B	S	B
A	6.6	6.4	6.2	2.8	6.8	6.7
B	6.5	6.4	6.3	3	6.9	6.3
C	5.2	5.2	5.3	2.8	—	—
D	7.6	7	5.8	3	6.8	5.8
E	5.5	6.2	5.5	2.9	—	—
F	6.4	5.9	5.6	2.9	6.5	6.4
G	6.3	5.1	4.8	1.9	—	—
H	5.3	4.3	4	2.9	6.3	5.8

S = surface; B = bottom

Lateral variations of DO at sts A to H are given in Table 4. Except during September, there was no regular increase in DO from st H to A. DO levels, however, were somewhat lower at st H.

A comparison of DO profiles in Fig. 6, reveals differences in the variation of DO at st 18 as compared to the other stations. The values fluctuated randomly and varied from 0 to 4 mg/litre. This range is below the level required for the healthy growth of marine life. Mahim Bay where st 18 is located, appears to be the most polluted area of the Bombay waters. This bay which extends a few kilometres inside the coast receives about 160 mld of waste water from the nearby sewage treatment plants and pumping stations. The pollution load is more than the bay water can assimilate efficiently which is evident from the DO levels.

Steep vertical gradient of DO was frequently observed at st 18 during the ebb tide. During the flood slack, the surface and bottom water had similar DO. But during the ebb tide as the level fell at the bay entrance, water of lower salinity and low DO from the upper reaches of the bay advanced to st 18 and formed the surface layer. Eventually, surface layer had lower DO than the bottom layer.

At the Back Bay (st 19) the average DO varied from 2 to 9.1 mg/litre. As in the case of Thana Creek stations, September was characterised by low DO (4 mg/litre) increasing up to about 9 mg/litre during February which decreased to about 5.3 mg/litre during May. Pronounced vertical gradient was observed during August. Surface water (sal. $27.5^{o}/_{oo}$) had DO of 2 mg/litre. The difference, however, decreased appreciably in the postmonsoon period.

BOD at the coastal stations varied from 0.2 to 2.3 mg/litre. Maximum BOD of 82 mg/litre was observed in May and June at 18a during neap tide. BOD levels at Worli Bay ranged from 0.8 to 8.3 mg/litre, the higher values being observed during the ebb slack.

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Haematological Changes in Kuwait Mullet, *Liza macrolepis* (Smith),Induced by Heavy Metals

M M HELMY, A E LEMKE, P G JACOB & Y Y AL-SULTAN
Earth & Environmental Sciences Division and Central Analytical Laboratory, Kuwait Institute for Scientific Research
P.O. Box-35150, Kuwait

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Toxic effects of copper (0.1-1.8 mg), lead (1.2-18.4 mg) and mercury (0.04-0.59 mg) on *L. macrolepis* were studied in a continuous flow-through system. On 96 hr exposure to different concentrations of lead, a significant ($P < 0.01$) decrease in activities of erythrocyte delta-amino levulinic acid dehydratase and plasma glutamic-oxalacetic transaminase was noted, decrease in the former being highly dose related. Mercuric chloride above 0.29 mg/litre caused increase in the blood *p*H, osmolarity, and total proteins. Copper induced a marked increase in plasma glucose and blood lactate contents.

Toxicity of heavy metals to animals is well documented[1,2] but as to fish the information is scanty[3,4]. In the present investigation, haematological changes induced by different doses of copper, lead and mercury in the Kuwait Mullet, *Liza macrolepis* (Smith), have been studied. These heavy metals are among the widespread pollutants in Kuwait, especially in the aquatic environment[5,6].

Materials and Methods

Fingerlings of the Kuwait mullet were used as indicator organism in this investigation because of their widespread distribution, easy accessibility and economic importance.

The animals were collected from wild populations in the vicinity of KISR Marine Bioassay and Toxicology Unit, acclimated for 1 week and then randomly distributed in test acquaria. Food was withheld 24 hr before testing. Sea water used in these experiments was drawn from Kuwait Salmiyah Head, Arabian Gulf, with the general characteristics: temperature 24 ± 1°C, salinity $35 \pm 1^{\circ}/_{oo}$, dissolved oxygen 5.8 ± 10.5 mg/litre and conductivity 20.05×10^4 μmho. The dissolved O_2 of each test solution was maintained at > 6 mg/litre by minimal aeration.

The short-term (96 hr) exposures to copper (as $CuSO_4.5H_2O$), lead [$Pb(NO_3)_2$] and mercury ($HgCl_2$) were carried out utilizing the serial diluter described by Mount and Brungs[7].

Dissolved oxygen was measured in 4 tanks each day and all other water characteristics of the exposure systems were monitored in 1 tank daily. The daily photoperiod lasted for 12 hr starting from 0645 hrs.

Samples for copper were acidified and analysed for total copper using the method described by Arthur and Leonard[8]. Total mercury in the test solution was analysed by the flameless atomic absorption technique[9]. Hach spectrophotometric method was used for the estimation of lead concentrations in water[10]. Each test concentration varied by not more than ±1 μg/litre from the scheduled nominal value.

All determinations of mortality or moribundity of the animals tested were made visually at the end of 96 hr exposure. The criterion for death was set at that point where there was no longer opercular action and the fish could not be stirred to movement by its removal from the tank. The 96 hr-LC_{50} was determined[11].

Blood sampling was made on a minimum of 12 representative fish in each concentration replicate. Blood was obtained by transaction of the caudal area posterior to the anal fin[12].

The osmotic activity (mosmols/litre) was determined by vapour pressure osmometer (Mechrolab Model 201 A), using 100 μl plasma diluted with 300 μl water following the procedure described in the manual.

Blood *p*H values were obtained by electrometric *p*H-meter at 37°C and calculated at 10°C; bicarbonate was determined titrimetrically.

Plasma total protein and chloride were determined on duplicate samples from each fish using the Beckman-Spinco 150-Ultramicro analytical system and the analytical procedures designed for this system. The control serum, Monotrol-I (Dade Reagents, Inc. Miami, USA) was used as a standard.

Plasma glutamic-oxalacetic transaminase (PGOT, L-asparate: 2-oxoglutarate amino transferase) was determined according to the method described by Frankel and Reitman[13] and modified by McKim *et al.*[14], including reduction by 10 times the volumes of reagents and sample, using Monotrol-I and Enzatrol as standards.

Activity of erythrocyte delta amino levulinic acid dehydratase (ALA-D) was assayed by the technique of Garnick *et al.*[15] and modified by Hodson[16]. Activity as units/ml of RBCs/hr was calculated according to Burch and Siegal[17] from absorbance, hematocrit, and reaction time.

Results and Discussion

In fish exposed to toxic doses of mercury, soon after the period of hyperactivity, some fish began to exhibit abnormal orientation. The first common noticeable symptoms were general darkening of body colour accompanied by formation of vertical bars. A short time later some fish were observed swimming at the surface in an upside-down position and others were in a vertical position, facing the water's surface.

For copper, symptoms started with fish rising toward the surface of water, followed by a period of hyperactivity characterised by rapid pectoral and opercular actions, erratic swimming or darting, and a gradual loss of equilibrium. After 1 or 2 days, some of the fish which had shown the above symptoms sank to the bottom of the aquaria and began erratic movement on their dorsal surface.

The only remarkable symptom for lead toxicity was darkening of body colour followed by some sporadic movements with decrease in the activity and fish exhibited only slow opercular movements. Subsequently, the slow opercular or breathing movements ceased and death occurred.

Comparison of the degree of toxicity for *L. macrolepis* based on LC_{50} (Table 1) showed that mercury was highly toxic followed by copper and lead, which is in agreement with the results of other investigators[18-23].

The onset of lethality was very rapid in mercury followed by lead and copper (Table 1), a fact pointing to functional if not material accumulative effects[24-31].

Minimal effective concentration for mercury was 5.6 times less than the LC_{50} under the same conditions of experimentation.

Since all the fish used in experiments have essentially the same morphological features, and since one would not expect individuals of a given species to differ greatly in their physiology or behaviours, it is difficult to predict any differences between the group of surviving fishes investigated and those that died from the effect of metals. It is possible that the resistance exhibited by individual fish in the surviving group may be the result of differences in mucus secretion, circulation, or other mechanisms controlling the entrance and distribution of metals.

Blood enzyme activities and chemical constituents are presented in Table 2.

Table 1—Toxicity Effects in *L. macrolepis* Exposed for 96 hr to Copper, Lead and Mercury

[Number of fish exposed in each treatment is 240 with length 6.2 to 6.8 cm. Values are expressed in mg/litre]

	Copper	Lead	Mercury
Doses	0.1-1.8	1.2-18.4	0.04-0.59
MEC (LC_0)	0.5	9.2	0.07
LC_{50}	1.4	14.6	0.38
LC_{100}	1.8	18.4	0.59
Initial mortality on day	3rd	2nd	1st

No distinctive pattern of variation was seen among plasma osmolarity or blood *p*H. Slight non-significant increase in both parameters was detected at higher concentrations of mercury after 96 hr exposures. Plasma chlorides and bicarbonates, on the contrary, were highest (132.3 and 9 mg/litre, respectively) among the fish exposed to mercury and this increase was correlated with the concentration. The values in fish exposed to lead were slightly above those in controls.

By contrast, both plasma chloride and bicarbonates tended to be somewhat lower among fish exposed to mercury.

In fishes, blood *p*H alone does not reliably reflect the acid-base status. Not much attention is paid to the fact that $pH + pOH = 10^{-14}$ only at 24°C. The expression of blood $pH - pOH$ or its antilog, the $(OH^-)/(H^+)$ ratio, allows an estimation of the range of acidosis and alkalosis at any environmental temperature. Thus a juvenile Kuwait mullet with a blood *p*H of 7.5 might be normal or even acidotic depending on the water temperature.

The hyperproteinemia noted from lethal concentrations of mercury was also observed in very slight degree with maximal lead concentrations.

Data of the type obtained in the present study do not prompt rigorous functional analysis. Nevertheless, some limited interpretation of possible mechanisms underlying seems appropriate. Except for lead, there was nearly constant increase in glucose and lactate which certainly reflects response to functional trauma rather than an effect of metal[32]. Elevated blood sugar levels in fish exposed to a variety of situations were considered as stressful[33].

Studies on the blood and carbohydrate metabolism[34,35], on coho salmon (*Oncorhynchus kisutch*) exposed to kraft effluents showed that glucose levels were elevated during acute exposures. The hyperglycemia can be caused by increased levels of circulating harmones[36-38]. Such change appears to have been associated with increased adrenal activity after generalized stress[39-41].

The decreased hyperglycemic responses of Kuwait mullets exposed to lead relative to the controls might

Table 2—Enzymatic Activities and Chemical Constituents of Blood of *L. macrolepis* Exposed to Varying Doses of Lead, Mercury and Copper for 96 hr

[Values are mean ±SE]

	Dose (mg/litre)	PGOT*	ALA-D[f]	Osmalarity (mosmols/ litre)	*p*H (at 10°C)	Chloride (mg/litre)	Bicarbonate (meq/litre)	Protein (g/100 ml)	Plasma glucose (mg/100 ml)	Blood lactate (mg/100 ml)
Lead	Control	15.2	261.2±59.7	286.3±14.6	7.51±0.7	123.5± 9.5	9.4±0.7	5.6±2.0	65.7±5.2	4.9±0.6
	1.15	12.2	211.6±40.8	284.2±16.4	7.50±0.7	125.7±16.4	9.1±1.4	5.9±1.3	62.8±3.6	3.4±0.5
	2.29	9.3	—	288.2±11.4	7.50±0.7	128.4±13.4	10.2±0.5	6.1±2.2	51.3±4.2	3.6±0.9
	4.59	—	194.5±48.2	295.6±11.3	7.79±0.8	130.3±14.5	11.6±0.8	5.8±1.9	53.7±4.5	2.9±0.7
	9.18	—	162.3±47.1	294.5±16.5	7.81±0.3	128.2±12.6	11.6±2.0	6.3±2.6	50.1±4.3	3.2±0.4
	18.36	5.6±3.3	187.8±49.0	300.1±19.6	7.82±0.9	129.8±12.7	10.9±1.2	6.3±1.8	50.0±4.4	3.0±0.3
Mercury	Control	12.7±1.3	272.9±42.3	293.3±10.2	7.51±0.6	120.9±12.3	9.6±0.4	5.9±1.4	67.3±7.1	4.2±0.6
	0.037	12.5±4.2	—	288.3±12.0	7.42±0.5	111.9±15.1	9.3±0.8	5.8±1.7	69.2±4.1	4.2±0.8
	0.074	—	265.5±53.0	284.0±12.7	7.59±0.7	107.4±10.9	9.0±1.0	5.6±1.9	72.0±5.7	4.5±0.8
	0.148	11.9±3.7	—	296.2±11.8	7.58±0.9	109.9±13.5	9.4±0.9	5.9±2.3	73.2±4.7	4.7±0.5
	0.295	9.7±2.4	251.0±53.7	320.1±19.1	7.84±0.4	128.0±17.1	9.1±3.2	7.4±1.9	75.7±4.1	4.8±0.6
	0.590	9.4±2.9	253.2±52.1	340.6±20.8	7.77±0.5	132.3±11.3	9.0±2.3	8.2±2.8	76.1±3.8	5.1±0.7
Copper	Control	13.3±0.9	266.3±48.8	291.1±12.0	7.66±0.6	125.8± 9.5	9.4±0.7	5.8±1.6	66.9±6.5	5.3±0.5
	0.11	—	267.3±52.9	290.0±13.9	7.55±0.5	125.8±10.4	10.9±1.5	5.7±1.5	67.8±4.4	5.4±0.5
	0.22	13.8±4.6	—	291.1±15.1	7.63±0.6	128.6±16.0	9.3±0.6	5.6±1.4	66.6±3.8	5.6±0.8
	0.42	—	272.5±51.5	287.4±15.0	7.72±0.7	130.7±11.7	11.5±0.6	5.7±1.6	69.5±3.9	5.6±0.7
	0.90	10.1±5.0	—	288.2± 9.3	7.65±0.6	130.4±15.8	12.7±2.8	6.0±2.4	68.9±5.0	6.0±0.4
	1.80	10.7±3.8	276.7±54.4	290.1±18.2	7.77±0.4	132.8±14.6	12.8±4.5	5.8±1.9	69.0±4.3	5.7±0.7

*Reitman-Frankel units/ml; [f] units/ml RBCs/hr

— = Not estimated

be due to differences in initial liver glycogen levels of the fish stock or specificity in lead metabolism.

The exact pathological effects of high concentrations of metals are not well understood, but the activity of serum enzymes may provide a useful index to cell destruction[42–44].

PGOT activity decreased on exposure to lead irrespective of the concentration applied. The time of exposure seems to be the influencial factor in this respect. ALA-D was more sensitive to lead and the change was dose dependent. Activity of ALA-D has been reported as a short-term indicator of long-term toxicity to fish[16]. After 4-5 days, 200 μg/litre of lead in water caused 50% inhibition of erythrocyte ALA-D of goldfish (*Carassius auratus*)[45], while 13 μg/litre inhibited the enzyme in rainbow trout (*Salmo gairdneri*) within 4 weeks[16]. Hodson *et al.*[46], reported that inhibition of ALA-D and its sensitivity were maximum at *p*H 6.4, while Burch and Siegel[17] explained the variability in buffer systems.

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Influence of Some Oceanographic Conditions on the Fisheries Off Mukka-Kaup along South Kanara Coast

S BENAKAPPA, M P M REDDY & V HARIHARAN
College of Fisheries, University of Agricultural Sciences, Mangalore 575002

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Surface water temperature and salinity have direct effect on the pelagic fisheries of oil sardine and mackerel. Water temperature plays a dominant role in the fluctuation of demersal fisheries, while only the deficiency of dissolved oxygen of bottom waters affects it.

The South Kanara coast on the west coast of India is endowed with rich fishery resources and is traditionally noted for the pelagic fisheries of oil sardine and Indian mackerel. In addition, the tapping of the demersal fishery resources, particularly the penaeid prawns, has significantly progressed along this coast. Several studies carried out earlier on the correlation of oceanographic conditions with fisheries along this coast are of general nature covering a greater area along widely spaced profiles. In the present investigation, studies have been carried out off Mukka-Kaup along South Kanara coast to find out the possible influence of some oceanographic conditions on the pelagic and demersal fisheries of the area.

Materials and Methods

Observations on sea water temperature, salinity and dissolved oxygen both at surface and near bottom, phytoplankton and zooplankton were made using standard techniques at 6 stations along 3 sections in the Arabian Sea off Mukka-Kaup region (Fig. 1). Two stations along each section were selected, one at 10 m (MK1, ML1, KP1) and the other at 20 m depth (MK2, ML2, KP2). The data were collected at monthly intervals from February 1977 to February 1978 except during June and July, when no collections could be made owing to rough seas. Simultaneously, bottom trawling was carried out, except in August, at 2 depths (10 m and 20 m) in the 4 zones of the area studied (Fig. 1), each haul being of 30 min duration. The weight of the total catch for each trawl was recorded. The present study was carried out within 20 m depth because maximum fishing activity of both mechanised and non-mechanised fishing boats is generally restricted to this depth. Data on monthly total landings of oil sardine and Indian mackerel at Baikampady, located just south of Mukka, were obtained from CMFRI Sub-Station, Mangalore. The data were considered as representative for the area between Mukka-Kaup as it is the only landing centre nearest to the region of study.

In order to find out the possible relationship, between oceanographic conditions and oil sardine and mackerel landings, the entire region between Mukka-Kaup within 20 m depth was considered as a single unit. The average values of the 6 stations in the 3 sections for surface water temperature and salinity, phytoplankton and zooplankton were calculated for each month. Similarly, to find out any possible relationship between the availability of demersal fish and the oceanographic conditions, the trawl catch weight of 4 hauls, bottom water temperature, salinity and dissolved oxygen values at 6 stations were averaged for the area between Mukka and Kaup during each month.

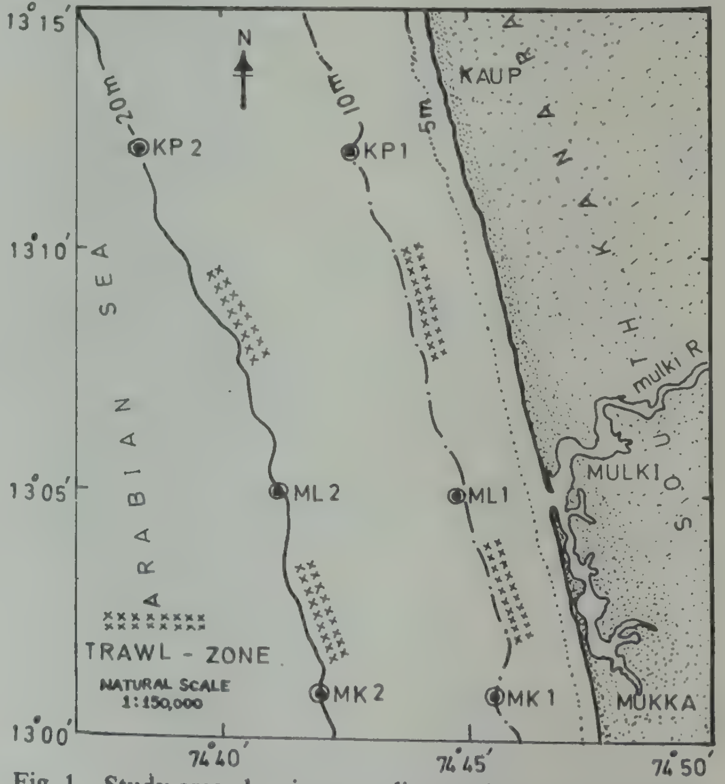

Fig. 1—Study area showing sampling stations and trawl zones

Results and Discussion

Pelagic fisheries and oceanographic conditions—Fish prefers certain optimum combination of physical and biological conditions in the environment for good production[1-5]. The oil sardine landings off Mukka-Kaup were relatively high during February, October and November 1977 (Fig. 2). The average surface temperature and salinity values for the corresponding months varied between 29.86 and 30.15°C and 32.75 and 33.5‰ respectively. Similar optimum values of temperature and salinity for good oil sardine fishery along the other parts of the west coast of India have been suggested[6-8]. In the present study, the ranges of temperature and salinity were narrow compared to earlier studies along the west coast and this may be due to the difference in the tolerance limits of different age groups. However, this view has to be confirmed by making observations on the sizes of the oil sardine catches.

Similarly, for mackerel relatively good landings were recorded from October to December 1977 and during February 1978. During this period the average surface temperature and salinity ranged between 28.36 and 30.15°C and 32.89 and 33.85‰ respectively (Fig. 2). These values may be taken as optimum values and any deviation from these may be responsible for the decrease in mackerel catches. While discussing the mackerel landings in relation to the hydrographical conditions at Calicut, Pradhan and Reddy[9] observed that the tolerance ranges of hydrographical factors may be different depending on the size of the mackerel. The optimum values found in the present investigation are in general agreement with the previous observations along the west coast of India[10].

An attempt has been made to correlate the standing crop of phytoplankton with oil sardine landings. No exact relationship between oil sardine and phytoplankton was noticed (Fig. 2). As observed by Bensam[11] factors such as feeding and spawning impulses appear to play a role, if any, only secondary to temperature and salinity in influencing the movements of oil sardine.

Similarly, the mackerel landings and zooplankton did not show any definite relationship in the present investigation (Fig. 2). But it appears that even when the food available in any region is below the normal requirements, mackerel may prefer the medium with favourable conditions to areas of fish food with unfavourable conditions.

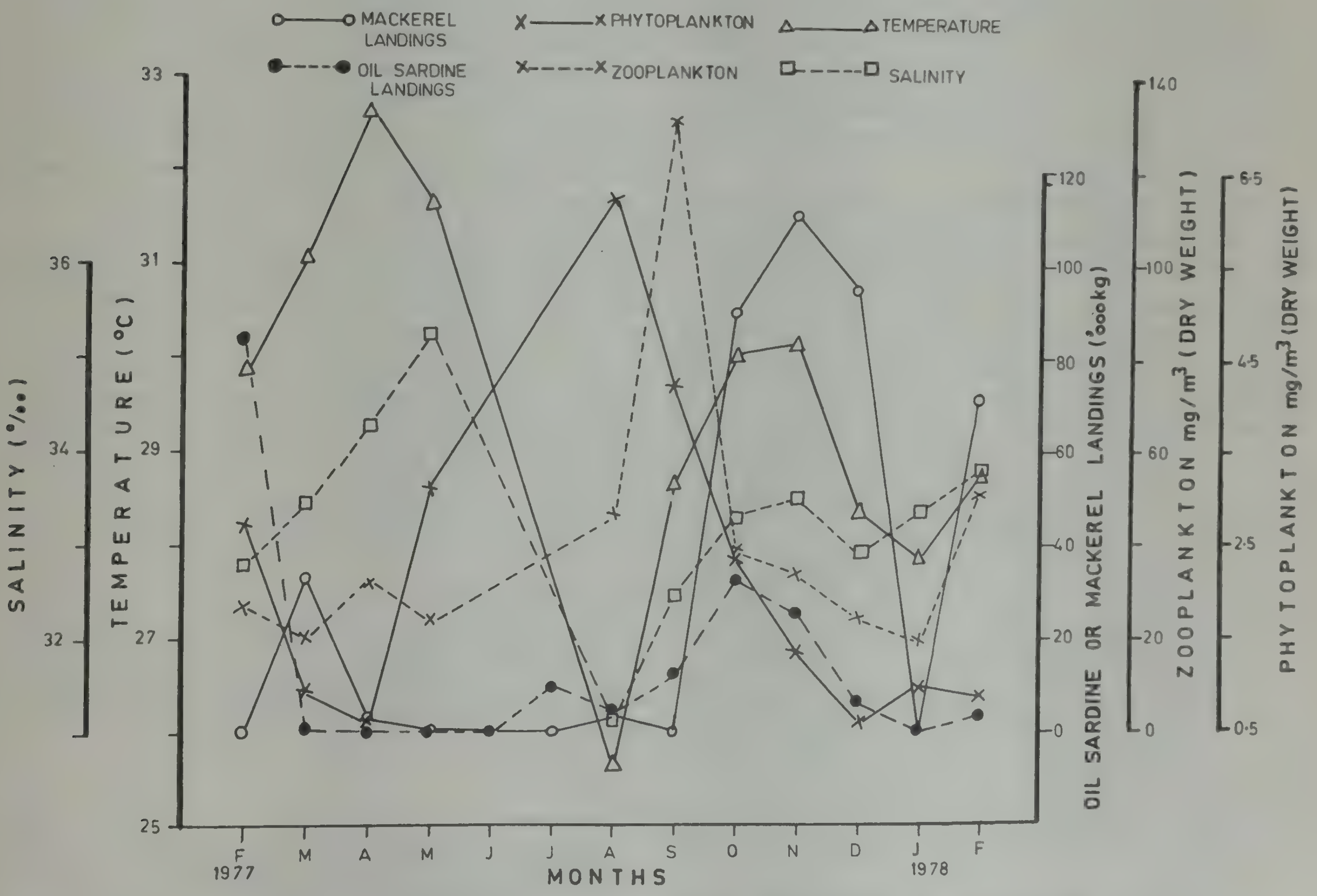

Fig. 2—Correlation between oceanographic parameters and oil sardine and mackerel landings

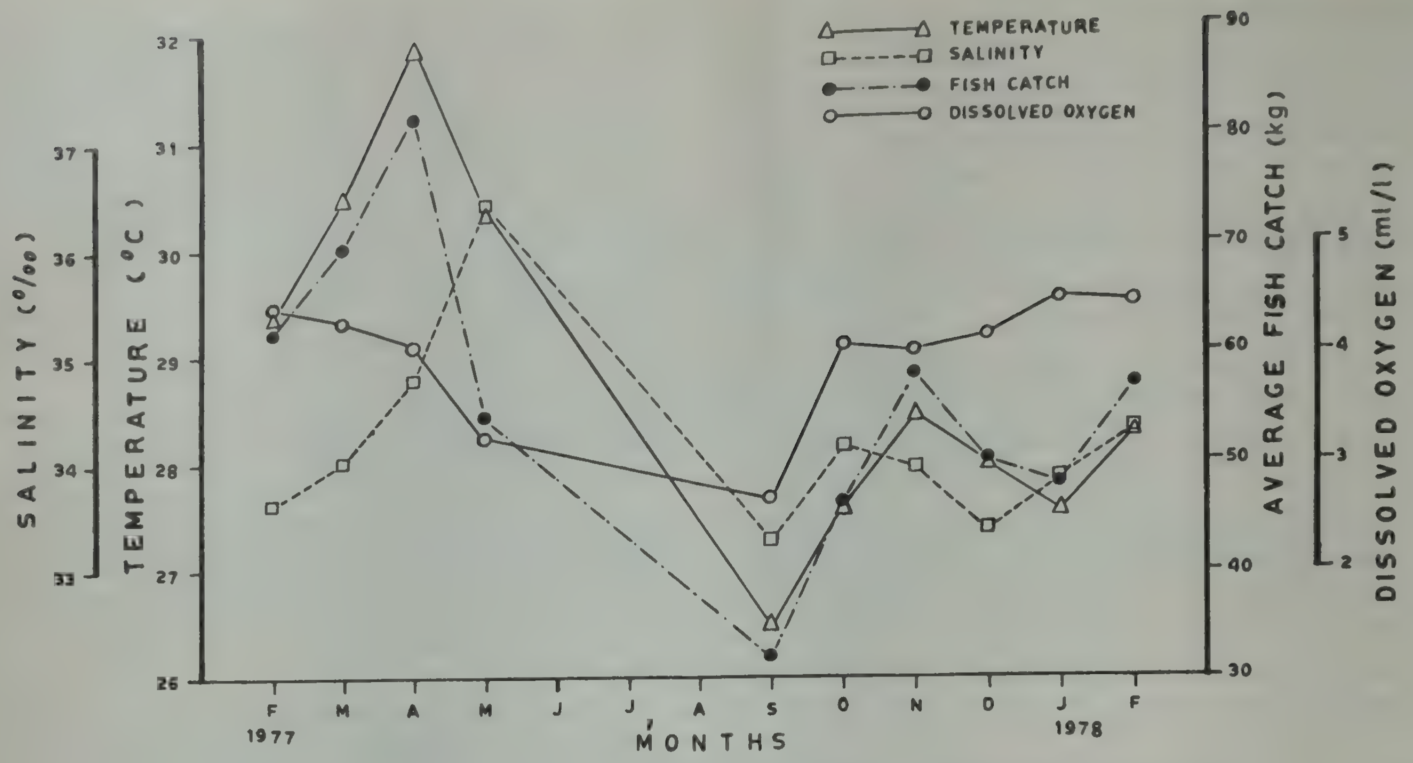

Fig. 3—Correlation between oceanographic parameters and trawl catches

Demersal fisheries and oceanographic conditions—There is a direct correlation between the bottom water temperature and demersal fisheries (Fig. 3). The findings of the present study, i.e. higher the bottom water temperature, better the trawl catch, are in agreement with the findings in middle and higher latitudes[12,13]. However, this relationship can hold good only till the maximum optimum temperature value is attained since all fish stocks have specific optimum temperatures.

Along the Maharashtra-Gujarat coast, the effects of bottom water temperature on the demersal fisheries were noted in the case of Dara and Koth fisheries[14]. Sankaranarayanan and Qasim[15] observed that seasonal changes in temperature and oxygen when plotted with fish and prawn catches off Cochin, the minimum values of temperature and oxygen at the bottom coincided with lowest fish and prawn catch. Maliel[16] observed a direct relationship between trawl fish catch and bottom water temperature fluctuations along the coast near Mangalore. In the present study the trawl fish catch was lowest in September when bottom water temperature touched the lowest of 26.48°C and highest catch was recorded in April when the temperature reached its peak value of 31.83°C.

The bottom water salinity showed, in general, a positive correlation with trawl catch except during May, November and January. In the present study, the effect of dissolved oxygen of bottom waters appears to be during May and September when the oxygen values were relatively low (Fig. 3), possibly due to the upwelling along this part of the coast during this period. That the demersal fishes are affected by the low oxygen content of the bottom waters was supported by the experience of the trawling operations off Cochin, according to which, with the onset of the southwest monsoon, the demersal fishes used to disappear suddenly from the shallow areas[17]. Carruthers *et al.*[18] found that during upwelling there is a layer of minimum oxygen, which has pronounced effect on marine life. In the present study, the lowest catch was in September when the dissolved oxygen recorded a minimum value. In May also trawl catch was relatively low compared to April and this could perhaps be due to the relatively low value of oxygen. The present investigation amply proved that only the deficiency of dissolved oxygen in the bottom waters can play a role on the demersal fishery and under normal conditions in the sea, dissolved oxygen content of bottom water does not become a limiting factor in the distribution of fish. Thus, during the observation months other than September and May, trawl catch variation is independent of dissolved oxygen content and no exact relationship exists between these 2 parameters.

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Distribution of *Vibrio parahaemolyticus* & Allied Vibrios in Backwater & Mangrove Biotopes at Porto Novo

R NATARAJAN, MARTIN ABRAHAM & G BALAKRISH NAIR
Centre of Advanced Study in Marine Biology, Annamalai University, Porto Novo 608 502

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Sediments proved to be the most stable ecological niche for survival of vibrios. Changes in populations of *Vibrio* spp in samples of water, plankton and sediment, obtained during March to May 1978, could be correlated to salinity. A qualitative survey of the incidence of *V. parahaemolyticus* in freshly caught finfish and shellfish revealed that a large percentage of animals sampled harboured the pathogen.

With the advent of the 'blue revolution', backwaters and mangroves have attained paramount importance as potential areas for culture of commercially esteemed species of finfish and shellfish. It is in this context that the present investigation on the occurrence of *V. parahaemolyticus*, the etiologic agent in foodborne gastroenteritis, in the mangrove and backwater environments was undertaken.

Materials and Methods

Three hydrobiologically distinct sites (sts I, II and III with average depths of 1.4, 1.8 and 1.1 m respectively) along a 10 km stretch of backwater and mangrove environs in the vicinity of Porto Novo (lat. 11°30′N; long. 79°46′E) were established and monthly collections carried out during March to May 1978. Samples of surface water, sediment and plankton were collected using Mac Cartney bottles, Petersen grab and horizontal tow plankton net respectively. Salinity was determined by Mohr's gravimetric method[1] and dissolved oxygen estimated by Winkler's titration[2]. *p*H and turbidity were measured using a portable Elico *p*H meter (Model L1-10) and Secchi disc respectively. All samples were brought to the laboratory for bacteriological analyses within 4 hr of collection. Bacterial counts were enumerated by the 3-tubes most probable number (MPN) technique[3]. Results (Tables 1 and 2) represent mean values for 2 samples of water, sediment and plankton taken at each station.

Appropriate decimal dilutions of water, plankton (after homogenising) and sediment samples were serially prepared using sterile 50% seawater. For enumeration of total aerobic heterotrophic bacteria (THB) 1 ml portions were inoculated in triplicate into screw cap tubes containing 10 ml sea water yeast extract (SWYE) broth and incubated at room temperature (27°C) for 48 hr. Subsequently a loopful of culture from all positive tubes showing growth was streaked onto thiosulfate citrate bile salts sucrose (TCBS) agar plates and incubated at 37°C for 18 hr.

For a qualitative survey of the occurrence of *V. parahaemolyticus* in seafoods, fish, prawns and crabs were caught by cast net operation. Oysters (*Crassostrea madrasensis*) were sampled both from the oyster bed at st III and from the roots of *Rhizophora* plants. Animals were first rinsed with sterile seawater to remove adhering mud and sand particles. For isolation of bacteria different regions of each specimen were swabbed with presterilised cotton swabs. The swabs were then put into test tubes containing 5 ml glucose salt teepol broth (GSTB) enrichment medium and incubated at 37°C for 6 hr. A loopful of culture from each tube was then streaked onto TCBS agar plates.

Bacterial colonies appearing on TCBS agar plates were categorised following the presumptive identification scheme of Kaneko and Colwell[3], i.e. colonies appearing on TCBS plates were regarded as *Vibrio*-like organisms (VLO) and 'typical' green colonies as *V. parahaemolyticus*-like organisms (VPLO). All VPLO isolates selected for further characterisation were restreaked to ensure purity and maintained at room temperature on SWYE agar slants. Identification of *V. parahaemolyticus* was based on the battery of diagnostic tests recommended by Hugh and Sakazaki[4].

Results

The physico-chemical parameters measured during the investigation are presented in Table 1. The lowest and highest salinities were recorded at st I (March) and st II (May) respectively. Due to the shallow nature of

Table 1—Physico-chemical Parameters Monitored from March to May 1978

Month	Salinity ($^{\circ}/_{oo}$)	Temp. (°C)		Dissolved oxygen (ml/1)	*p*H		Turbidity (m)
		Water	Sediment		Water	Sediment	
				St I			
March	12.6	29.5	28.5	6.3	8.1	7.6	0.27
April	20.4	34.5	34	5.9	7.95	7.75	0.22
May	28.3	30.5	29.5	6	7.85	7.55	0.4
				St II			
March	22.8	29	28.5	6.8	8.15	7.55	0.48
April	28.1	33	33	5	8	7.45	0.75
May	30.1	30	29.5	6.8	8	7.5	0.51
				St III			
March	20.9	30	29	7.7	8.1	7.6	0.39
April	25.7	32	32	4.9	7.8	7.45	0.41
May	28.6	30	29.5	6.2	7.95	7.15	0.37

the sampling sites, differences between the temperature of surface water and bottom sediments were never >1°C at any one collection.

Results of bacteriological analyses (Table 2) show that the THB count of samples from all 3 stations was fairly constant. In contrast populations of VLO, VPLO and *V. parahaemolyticus* exhibited distinct patterns of abundance in space and time.

Results of bacteriological analyses of freshly caught finfish and shellfish are presented in Tables 3 and 4. Occurrence of *V. parahaemolyticus* associated with animals was consistently high. Frequency of recovery of *V. parahaemolyticus* from the different regions swabbed showed marked variations in the positive specimens of each animal group.

Discussion

Seasonal and geographical distribution of *V. parahaemolyticus* in natural habitats seem to be primarily dictated by water temperature[3,5], organic nutrient content[6,7] and abundance of zooplankton[3]. The effects of salinity, temperature, *p*H and other unidentified factors influencing the attachment to zooplankton and growth and survival of *V. parahaemolyticus* may be responsible for its distribution being restricted to estuaries and neritic environments[8]. Results of the present investigation indicate that salinity is the principal parameter governing the distribution and abundance of *V parahaemolyticus* and allied organisms in the backwater and mangrove biotopes of Porto Novo. Water samples show higher counts of VLO, VPLO and *V. parahaemolyticus* at lower salinities while at salinities >28$^{\circ}/_{oo}$ only poor counts of these bacteria are observed. The association of *V. parahaemolyticus* and

Table 2—Counts of Total Aerobic Heterotrophic Bacteria (THB), *Vibrio*-like Organisms (VLO), *V. parahaemolyticus*-like Organisms (VPLO) and *V. parahaemolyticus* (VP) in Water (per 10 ml), Sediment (per g) and Plankton (per g) Samples from March to April 1978

Month	Sample	THB	VLO	VPLO	VP
		St I			
March	Water	7.8×10^7	5.9×10^5	3.1×10^3	3.1×10^2
	Sediment	8.0×10^7	9.7×10^4	8.4×10^3	4.3×10^3
	Plankton	3.5×10^7	2.4×10^7	8.4×10^4	5.9×10^4
April	Water	9.3×10^8	1.8×10^5	3.1×10^4	5.9×10^3
	Sediment	3.1×10^8	7.9×10^6	8.7×10^4	4.9×10^3
	Plankton	9.8×10^8	1.8×10^6	9.5×10^5	3.1×10^4
May	Water	8.4×10^8	6.8×10^3	3.1×10	0.4×10
	Sediment	5.8×10^7	8.0×10^5	8.2×10^3	5.2×10^2
	Plankton	2.3×10^7	7.0×10^4	4.1×10	2.3×10
		St II			
March	Water	8.4×10^7	3.5×10^4	5.9×10^3	3.1×10^3
	Sediment	7.8×10^8	5.9×10^6	7.8×10^3	2.3×10^3
	Plankton	8.4×10^7	9.5×10^5	3.3×10^4	3.1×10^3
April	Water	5.9×10^8	7.0×10^3	9.3×10	1.2×10
	Sediment	3.5×10^8	8.7×10^5	3.3×10^4	5.7×10^2
	Plankton	9.5×10^7	6.8×10^3	9.2×10^2	5.7×10
May	Water	8.4×10^7	8.2×10^2	2.5×10	0
	Sediment	5.8×10^7	5.9×10^2	4.3×10^2	2.3×10^2
	Plankton	1.2×10^7	6.8×10^4	8.4×10	2.3×10
		St III			
March	Water	5.9×10^6	8.4×10^3	7.9×10^2	3.1×10
	Sediment	3.1×10^8	8.4×10^6	5.4×10^4	9.7×10^2
	Plankton	3.4×10^8	9.7×10^5	3.3×10^5	8.4×10^3
April	Water	9.7×10^6	9.2×10^2	5.9×10	3.3×10
	Sediment	3.5×10^8	8.0×10^4	4.9×10^3	8.4×10^2
	Plankton	9.8×10^7	9.7×10^4	6.8×10^4	4.9×10^2
May	Water	7.8×10^6	4.1×10^2	8.4×10	0.7×10
	Sediment	2.0×10^8	5.9×10^3	9.7×10^2	2.3×10^2
	Plankton	7.8×10^8	9.5×10^5	6.8×10^2	6.7×10

Table 3—Occurrence of *V. parahaemolyticus* in Finfish and Shellfish Caught in the Study Area from March to May 1978

	Number of specimens examined	Number positive for *V. parahaemolyticus*	% positive
		March	
Fish	17	7	41.2
Prawns	13	7	53.8
Crabs	10	3	30
Oysters	16	7	43.8
		April	
Fish	19	7	36.8
Prawns	16	8	50
Crabs	12	5	41.7
Oysters	13	9	69.2
		May	
Fish	25	11	44
Prawns	14	6	42.9
Crabs	9	4	44.4
Oysters	15	10	66.7

Table 4—Distribution of *V. parahaemolyticus* in Various Regions of Finfish and Shellfish Caught in the Study Area from march to May 1978

Total No. of specimens positive for *V. parahaemolyticus*	Region of recovery in positive specimens		Per cent incidence of *V. parahaemolyticus* in different regions of positive specimens
	Fish		
25	External surface	8*	32
	Gills	12	48
	Faeces	19	76
	Prawns		
21	External surface	9	42.9
	Gills	10	47.6
	Haemolymph	17	81
	Crabs		
12	External surface	4	33.3
	Gills	8	66.7
	Haemolymph	6	50
	Oysters		
26	External surface	7	26.9
	Gills	18	69.2
	Mantle	11	42.3

*Frequency of occurrence of *V. parahaemolyticus* in the region specified

other chitinoclastic vibrios with zooplankton and their role in the recycling of nutrients via mineralization of copepod exoskeleton have been elaborately studied[3,8]. Shimidu *et al.*[9] and Kaneko and Colwell[3] have observed that in midsummer months the total viable count of plankton samples comprise almost exclusively of *Vibrio* spp. At all 3 stations, copepods form nearly 75% of the zooplankton population and this may account for the rather high counts of *V. parahaemolyticus* and related vibrios associated with plankton encountered during the March-April period (when favourable salinities prevailed). The observation that vibrios associated with plankton decreased gradually in numbers at high salinities concurs with earlier findings[8].

While populations of VLO, VPLO and *V. parahaemolyticus* in water and plankton exhibit distinct variations in abundance, the number of the above bacteria in sediments remains fairly constant. In temperate waters, it has been reported that *V. parahaemolyticus* survives the low temperatures of winter by overwintering in the sediments[3]. Hence it appears that sediments play a significant role in the annual cycle of *V. parahaemclyticus* and related organisms by serving a protective function. Whether other factors may also be involved in determining the seasonal abundance of *V. parahaemolyticus* and allied species needs further study.

Results presented in Tables 3 and 4 indicate that an alarmingly high percentage of the fish, crustaceans and oysters sampled harbour *V. parahaemolyticus*. Among these, oysters, possibly by virtue of their filter feeding habit, prove to be major reservoirs of the pathogen. From a public health view point the association of *V. parahaemolyticus* with commercially important species of finfish and shellfish is of interest since most outbreaks of gastroenteritis have been traced to consumption of contaminated seafoods. If the trends described in the present study hold good for other mangrove ecosystems as well, then any attempt to exploit the backwaters and mangroves as potential sites for aquaculture must be undertaken with utmost caution and regular bacteriological monitoring.

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Short Communications

Association of a Bivalve with Mollusc

V O SEBASTIAN

Department of Marine Sciences, University of Cochin, Cochin 682016

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Presence of the lamellibranch, *Modiolus metcalfei* (Hanley) within the test of the ascidian, *Herdmania pallida* (Heller) is reported. It is likely that *M. metcalfei* gets protection from predators because of this association.

Several animals are associated with different species of ascidians. Some of them have become parasites on the ascidians while others remain as commensals or symbionts[1].

Among the commensals, molluscs form an important group. Several gastropods and lamellibranchs are found lodged within the test of ascidians[2-5]. Occurrence of lamellibranch mollusc within the test of *Herdmania pallida* (Heller) and *H. momus* (Savigny), collected from the sea adjoining Tuticorin, has been reported[6,7]. The settlement of the molluscan larvae on the ascidian may be stimulated by a chemical secretion, and it is found that the settlement takes place even when an eviscerated test is offered.

The association of a bivalve with an ascidian was noticed during collections of *Herdmania pallida* from the Tuticorin seas. A number of large-sized *H. pallida* were cut open for study and most of them had the lamellibranch, *Modiolus metcalfei* (Hanley) within their tests (Fig. 1). *M. metcalfei* is of common occurrence along the east coast of India[8]. The number of these molluscs varied in individuals, maximum being 10. They were found lodged in all parts of the test. Within the left half there are 3 *Modiolus*, and part of their shells project out on the inner side of the test because this part of the test is comparatively thin (Fig. 1). Within the right half 7 *Modiolus* are lodged, but the test being thicker only 4 of the molluscs are dimly visible to the eye, the others being hidden by the test substance.

The size of *H. pallida* (Fig. 1) was 9 cm × 7 cm × 3 cm. *M. metcalfei* showed different sizes, the biggest being 2.5 cm × 1.5 cm × 1 cm and the smallest, 2 cm × 1.2 cm × 0.8 cm. Considering the sizes of the mussel it is only reasonable to suppose that too many of them cannot thrive within the test of a single ascidian. The mussel is fully lodged within the ascidian test and no part projects outside. The outer side of the test opposite the

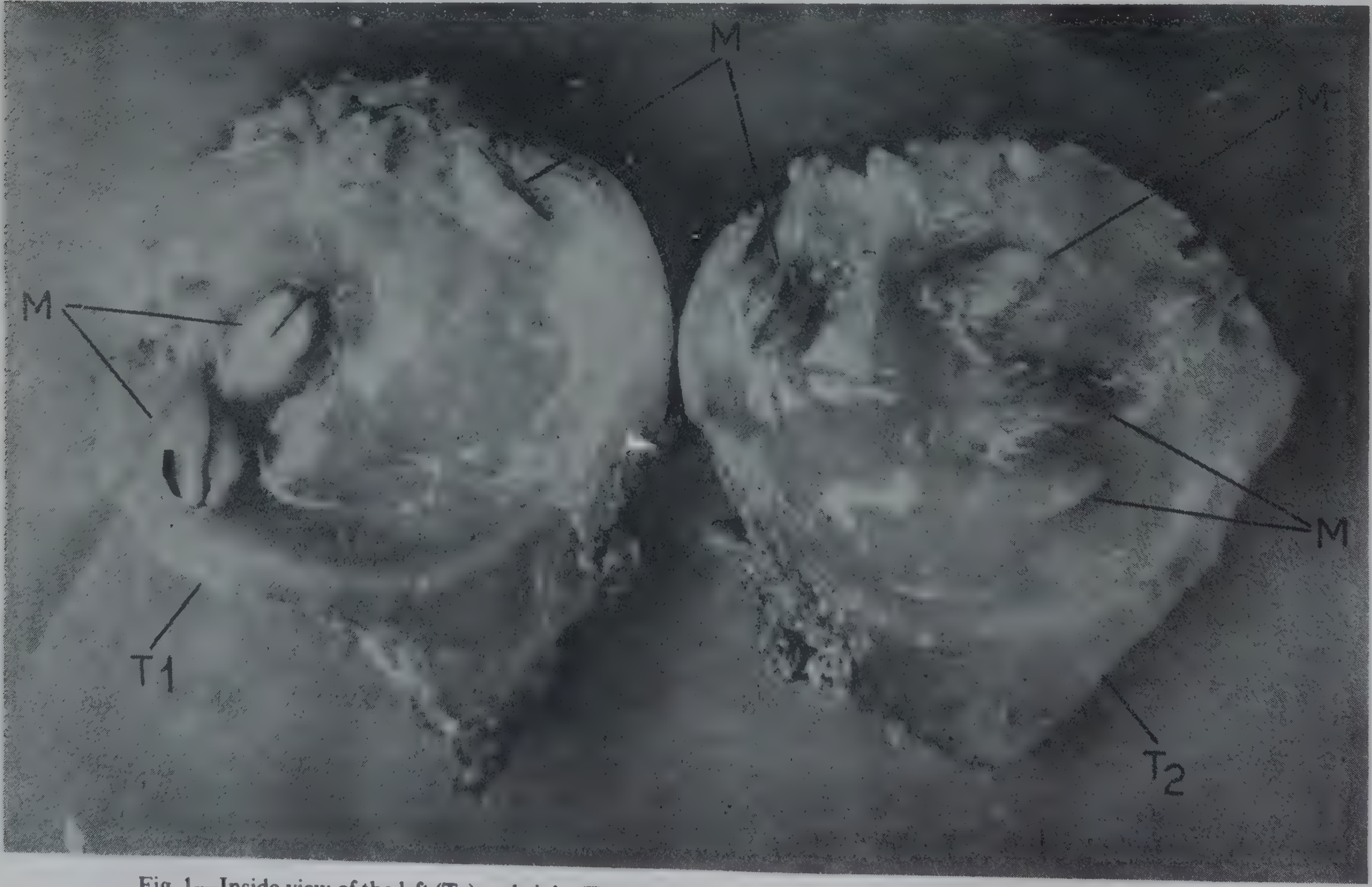

Fig. 1—Inside view of the left (T_1) and right (T_2) halves of the test of *H. pallida* (M, location of *M. metcalfei*)

place where the mussel is embedded shows a depression, and within it there is a short opening of about 0.5 cm through which the mussel communicates with the outside.

Is this association of *Modiolus* with *Herdmania* a case of commensalism or symbiosis? In commensalism there must be a benefit at least to one of the partners if not for both, and in symbiosis both partners are mutually benefitted. One of the chief advantages in such a partnership is the procurement of food. The ascidian is a fixed animal. The mussel is extremely slow moving, and when once it is attached to a substratum it does not move unless dislodged by external force. Both are filter feeders capturing food by their own effort, and so one is not benefitted by the other in any way. The term commensalism or symbiosis does not appear to be true in this sort of association. But the lamellibranch like *Modiolus*, lodged completely inside the test of the ascidian may get protection from predators like starfishes which can rip open the shells and consume the soft parts. It is more reasonable to consider the entry of *Modiolus* into the test of *Herdmania* by accidental contact of its settling larvae, in the same way as the ascidian larvae are found to settle on other animals like molluscs, barnacles, ascidians and so on.

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Marine Microplankton from Sierra Leone (West Africa)

A A ALEEM*

Institute of Marine Biology & Oceanography, University of Sierra Leone, Sierra Leone

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The microplankton species (141) inhabiting inshore and offshore waters of Sierra Leone comprise diatoms (95), dinoflagellates (42), silicoflagellates (2) and blue green algae (2). Diatoms are more abundant in inshore waters, while dinoflagellates are more frequent in offshore waters. Among epibionts on *Chaetoceros* a ciliate, *Vorticella oceanica*, and peridinian, *Paulsenella chaetoceratis*, are new records for the Gulf of Guinea. The common estuarine species of *Coscinodiscus* is established as *C. jonesianus* (Grev.) Ostenf.

Composition and seasonal variations of the microplankton of inshore and offshore waters of Sierra Leone (Fig. 1) are less known compared to other West African waters such as those of Senegal[1,2] or Ivory Coast[3]. Bainbridge[4] has described qualitative and quantitative changes in the plankton of the Sierra Leone River Estuary. Taylor[5] has added little more information on the phytoplankton of the same, while information on the microplankton in offshore waters remains almost unknown. Hydrography of Sierra Leone River Estuary is also known[6,7].

Preliminary studies on the inshore and offshore microplankton of Sierra Leone together with some ecological observations are presented in this communication. No attempt is made to quantitate the microplankton in this report.

Horizontal and vertical offshore plankton hauls were collected by Apstein or standard phytoplankton nets in various stations during the cruises of *R V Awefu* during February, May, November 1970 and January-March, June 1971. Inshore samples were collected more frequently during 1971 and 1972 by smaller crafts.

The mean monthly temperatures of surface water in Sierra Leone vary between 26.6 and 29.6°C. Seasonal changes in temperature and salinity in territorial waters are attributed to the precipitation cycle and wind. Southwest winds predominate in the Gulf of

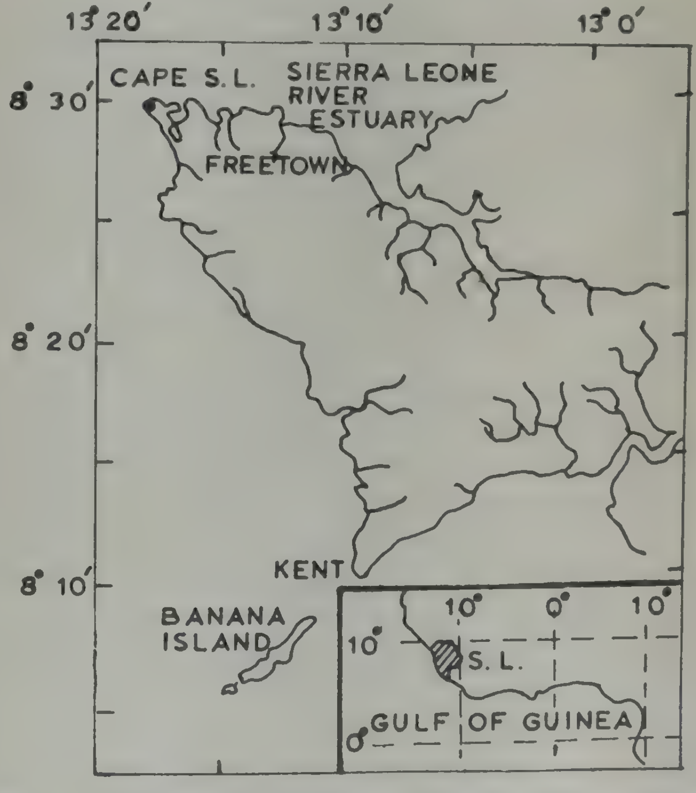

Fig. 1—Freetown Peninsula and Sierra Leone River Estuary [Inset shows location of Sierra Leone in the Gulf of Guinea]

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*Permanent address: Oceanography Department, Faculty of Science, University of Alexandria, Alexandria, Egypt

Guinea in summer with frequent rainfall. The area is characterized by 2 main seasons: A dry season extending from December to April and a rainy season from May to November. The heaviest rainfall, however, occurs from July to September. The total annual runoff from land in Sierra Leone is estimated as 90,000 million m^3. Surface salinity increases during the dry season to a maximum of 35‰ in April and is lower during the rainy season. Watts[6] has reported a salinity gradient during October from 24.8‰ at 16 km off Cape Sierra Leone to 32.8‰ at 120 km off this Cape.

The depth of thermocline varies between 10 m in inshore waters to about 20 m in offshore waters. Both nitrates and phosphates in the Sierra Leone estuary increase from 5 μg at-N/litre and 0.3 μg at-P/litre in the dry season to 10 μg at-N/litre and 0.97 μg at-P/litre in the rainy season in succession.

The area is characterised by upwelling during the dry season, which differs in intensity according to the relevant winds and current. Different groups of microplankton observed in the samples are given in Table 1.

Red water—Red water or 'red tide' is of frequent occurrence in offshore and inshore waters of Sierra Leone. It is due to the blue green alga *Oscillatoria thiebauti* which, under favourable conditions, divides rapidly and in large numbers. This takes place more often in the dry season than in the rainy season. Areas of water discoloured for several square kilometers have been observed during the cruises in February 1970 at a station situated *c* 60 km to the NW of Freetown (8° 55′ N & 13° 45′ W).

The colour of water during *Oscillatoria* blooms varies between faint orange and brownish, but is never as red as in the case of *Prorocentrum* or *Gonyaulax* blooms. Red water seems to develop under conditions of high water temperature and still wind, both contributing to a high stability of the water column. Red water also occurs in Sierra Leone River Estuary due to *O. thiebauti* but in no case the phenomenon is associated with fish mortality.

O. thiebauti in the waters of Sierra Leone occurs in the form of straight or flexuous filaments, which are either solitary or united together in the form of bundles. Cells are 5-16 μm broad and as long or even longer. During blooms, filaments also occur in the form of small balls or discs stuck together in a radial form around a central point. This as well as the common bundle-form may occur together in the same water mass.

Silva[1] and Seguin[2] have recorded red water due to blooms of *Noctiluca miliaris*. This species is also found in the present microplankton samples, though not in great quantities.

During red water blooms, other phytoplankton species are considerably reduced. The more common species associated with blooms that developed in February 1970 (relative abundance is given in parenthesis as: a, abundant; c, common; f, frequent; r, rare) are: *Oscillatoria thiebauti* (a), *Rhizosolenia bergoni* (f-c), *R. imbricata* (f-c), *Coscinodiscus centralis* (f-c), *Stephanopyxis palmeriana* (f-c) and *Chaetoceros atlanticum* (f-c).

Composition of inshore and offshore microplankton—The following diatom species dominate inshore and estuarine phytoplankton, at one time or the other: *Coscinodiscus* spp, *Hemidiscus cuneiformis, Thalassiosira subtilis, Coscinosira* sp., *Biddulphia sinensis, Triceratium alternans, Guinardia flaccida, Rhizosolenia* spp, *Cerataulina bergoni, Skeletonema costatum, Bacteriastrum hyalinum* and *Chaetoceros* spp. In addition to these a few species of benthic diatoms (*Nitzschia, Navicula, Pleurosigma, Amphora* and *Achnanthes*) are not infrequent in plankton catches.

Paucity of dinoflagellates in inshore and estuarine plankton is a marked character, except perhaps during upwelling or influxes of offshore water into the area off Cape Sierra Leone, when *Ceratium* and *Peridinium* spp, together with characteristic cladocerans, particularly *Penilia avirostris* and *Evadne tergestina* are encountered. The latter 2 species are important zooplankters during the dry season in inshore waters.

In the rainy season the phytoplankton, on the whole, is less developed than in the dry season. Factors contributing to this being (1) huge amounts of runoff from land with silt and mud causing turbidity of the water, which is also charged with plant debris stirred up from the bottom by the strong current during this season and (2) diminished light during July and August in particular, due to mist and clouds. However, light may not be the sole factor responsible for the relative poverty of phytoplankton in inshore waters as suggested by Bainbridge[4]. Composition and relative abundance (in parenthesis) of phytoplankton in the Sierra Leone River Estuary on 12 February 1970 are as follows: *Coscinodiscus jonesianus* (a), *C. lineatus* (f), *C. excentricus* (r), *Skeletonema costatum* (f-c), *Thalassiosira subtilis* (f), *Thalassiothrix frauenfeldi* (f), *Rhizosolenia cylindrus* (f), *Biddulphia sinensis* (f), *Paralia sulcata* (f), *Bacteriastrum hyalinum* (f), *Guinardia flaccida* (f), *Eucampia zodiacus* (r) and *Hemidiscus cuneiformis* (f-c).

Offshore plankton observed a week earlier at a station about 145 km offshore (8° 09′ N & 14° 05′ W, on the edge of the continental shelf) shows typical oceanic species with frequent occurrence of peridinians. Composition and relative frequency (in parenthesis) of the species observed are as follows: *Oscillatoria*

Table 1—Microplankton Composition

Family and Species
Coscinodiscaceae
Melosira (Paralia) sulcata (Ehr.) Kütz.
Stephanopyxis palmeriana (Grev.) Grun.
Skeletonema costatum (Grev.) Cl.
Cyclotella kuetzingiana Thw.
Coscinodiscus asteromphalus Ehr.
C. centralis Ehr.
C. excentricus Ehr.
C. gigas Ehr.
C. jonesianus (Grev.) Ostenf.
C. lineatus Ehr.
C. oculus-iridis Ehr.
C. perforatus Ehr.
Planktoniella sol (Wallich) Schutt.
Actinocyclus octonarius Ehr. var. *octonarius*
Roperia tessellata (Roper) Grun.
Thalassiosira subtilis (Osten.) Gran
T. decipiens (Grun.) Jrg.
Coscinosira polychorda (Gran)
Hemidiscaceae
Hemidiscus cuneiformis Wallich
Actinodiscaceae
Actinoptychus senarius Ehr. (*A. undulatus*)
Auliscaceae
Asteromphalus heptactis (Breb.) Ralfs
Asterolampra grevillei (Wallich) Grev.
Biddulphiaceae
Biddulphia aurita (Lyngb.) Breb.
B. longicruris Grev.
B. mobiliensis (Bail.) Grun.
B. regia (Schultz) Ostenf.
B. sinensis Grev.
B. laevis Ehr.
Triceratium alternans Bail.
T. favus Ehr.
Cerataulina pelagica (Cl.) Hendey (=*C. bergoni Per.)*
Hemiaulus haucki Grun.
H. indicus Karsten
Ditylum brightwellei (West) Grun.
Streptotheca tamensis Schrubs.
Eucampia zodiacus Ehr.
Chaetoceraceae
Chaetoceros atlanticum Cl.
C. tetrastichon Cl. (with *Vorticella oceanica* as epibiont)
C. peruvianum Brightwell
C. decipiens Cl.
C. compressum Lauder
Chaetoceros didymum Ehr.
C. affine Lauder
C. curvisetum Cl.
C. simplex Ostenf.
C. sociale Lauder
Bacteriastraceae
Bacteriastrum elongatum Cl.
B. delicatulum Cl.
B. hyalinum Lauder
DIATOMS
Leptocylindraceae
Leptocylindrus danicus Schütt
Guinardia flaccida (Castr.) Per.
Schroederella delicatula (Per.) Pavillard
Datyliosolen mediterraneus Per.
Corethronaceae
Corethron criophilum Castr. (=*C. hystrix* Hensen)
Rhizosoleniaceae
Rhizosolenia alata f. *gracillima* (Cl.) Gran
R. alata f. *indica* (per.) Gran
R. fragilissima Bergon
R. stolterforthi Per.
R. cylindrus Cl.
R. robusta Norman
R. shrubsolei Cl.
R. imbricata Brightwell
R. setigera Brightwell
R. styliformis Brightwell
R. hebatata Bailey
R. hebatata f. *semispina* (Hensen) Gran
R. calcar-avis Schultze
R. acuminata (Per.) Gran
R. bergoni Per.
R. castracanei Per.
R. delicatula Cl.
Fragilariaceae
Thalassiothrix frauenfeldi Grun.
T. longissima Cl. & Grun.
Thalassionema nitzschioides Hust.
Asterionella japonica Cl. et Moller
Synedra tabulata (Ag.) Kütz.
S. undulata (Bailey) Greg.
S. hennedyana Greg.
Licmophora gracilis (Ehr.) Grun.
Grammatophora marina (Lyngb.) Kütz.
Achnanthaceae
Achnanthes subsessilis Kütz.
Cocconeis placentula Ehr.
Campyloneis grevillei (Sm.) Grun.
Naviculaceae
Pleurosigma elongatum W. Sm
P. normanni Ralfs
P. strigosum W. Sm.
Gyrosigma littorale (W. Sm.) Cl.
Trachyneis aspera (Ehr.) Cl.
Tropidoneis lepidoptera Greg.
Cymbellaceae
Amphora hyalina Kütz.
A. decussata Grun.
Bacillariaceae
Bacillaria paradoxa (Gmelin) Grun.
Nitzschia closterium (Ehr.) Sm.
N. longissima Breb.
N. seriata Cl.

Contd

Table 1—Microplankton Composition —Contd

Family and Species

DINOFLAGELLATA

Prorocentraceae
Exuviella marina Cienkowski
E. baltica Lohmann
Prorocentrum micans Ehr.
Gymnodiniaceae
Amphidinium sp.
Gymnodinium sp.
Noctilucaceae
Noctiluca miliaris Suriray
Dinophysiaceae
Dinophysis acuminata Claperede et Lachmann
D. caudata Sav.
D. rotunda Clap. et Lach.
Phalacroma rotundatum Clap. et Lach.
Gonyaulaceae
Gonyaulax polygramma Stein
Peridiniaceae
Peridinium conicum (Gran) Ostenf. et Schmidt
P crassipes Kofoid
P. depressum Bailey
P. pentagonum Gran
Ceratiaceae
Ceratium candelabrum (Ehr.) Stein
C. furca (Ehr.) Clap. et Lach.
C. belone Cl.

Family and Species

Ceratiaceae
Ceratium fusus (Ehr.) Dujard. var. *fusus*
C. fusus var. *schuetti* Lemm.
C. inflatum (Kof.) Jrg.
C. tripos var. *atlanticum* (Ostenf.) Paulsen
C. tripos f. *hiemale* Paulsen
C. breve (Ostenf. et Schmd.) Schrod.
C. arietinum Cl.
C. symmetricum var. *orthoceros* (Jorg. Graham et Bron.)
C. azoricum Cl.
C. declinatum f. *normale* Jorg.
C. contortum (Gouret) Cl.
C. gibberum Gourret var. *subaequale* Jrg.
C. ranipes Cl.
C. macroceros (Ehr.) Vanhoffen
C. massiliense (Gourret) Jrg.
C. trichoceros (Ehr.) Kof.
C. contrarium (Gourret) Pav.
C. vultur Cl. f. *recurvum* (Jrg) Schiller
C. hexanthum Gourret
Podolampas bipes (Stein)
**Pyrocystis lunula* (Schutt)
Solenicola setigera (epiphytic on *Dactyliosolen*)
Paulseneila chaetoceratis (epiphytic on *Chaetoceros*)

SILICOFLAGELLATA

Distephanus speculum Ehr.
Dictyocha fibula Ehr.

CYANOPHYTA

†*Oscillatoria* (*Trichodesmium*) *thiebauti* Gomont
Richelia intracellularis (Johns.) Schmidt.

*The species occurs in 2 different forms (spherical and lunula) which are stages in the life cycle of the organism. Both forms occur in inshore and offshore waters.

†Species responsible for the Red Water, frequently observed during dry season[8].

thiebauti (f), *Rhizosolenia stolterforthi* (f), *R. delicatula* (r), *R. alata gracillima* (f), *R. calcar-avis* (r), *R. imbricata* (r), *R. cylindrus* (r), *Thalassiosira decipiens* (f), *Thalassionema nitzschioides* (f-c), *Thalassiothrix frauenfeldi* (r), *Biddulphia sinensis* (f), *Hemiaulus haucki* (f), *Corethron criophilum* (f), *Chaetoceros atlanticum* (f-c), *C. tetrastichon* (f-c), *C. decipiens* (f), *Cerataulina bergoni* (f), *C. pelagica* (f), *Stephanopyxis palmeriana* (f), *Planktoniella sol* (r), *Eucampia zodiacus* (f), *Nitzschia seriata* (f), *Ceratium symmetricum* var. *orthoceros* (r), *C. trichoceros* (f), *C. furca* (r), *Ceratium macroceros* (f), *C. azoricum* (r), *Peridinium crassipes* (f) and *P. depressum* (r).

The composition of phytoplankton in offshore water towards the end of the dry season changes considerably. Thus certain species become more frequent, while others appear as characteristic of the period. Peridinians become more conspicuous in numbers in the samples. Species observed (relative dominance in parenthesis) at a station about 45 km offshore (8° 30′ N & 13° 42′ W) on 14th April 1970 (vertical hauls from 10-0 m) are: *Chaetoceros atlanticum* (r), *Rhizosolenia hebatata* (r), *Leptocylindrus danicus* (r), *Actinocyclus octonarium* (f), *Ceratium massiliense* (f), *C. hexacanthanum* (f), *Phalacroma* sp. (f), *Peridinium crassipes* (r), *Dinophysis caudata* (f), *D. rotundatum* (f), *D. acuminata* (r), *Podolampas bipes* (r), *Distephanus speculum* (r), *Noctiluca miliaris* (f) and *Pyrocystis lunula* (r).

Zooplankton in these collections is rich in sagittas and salps, in addition to copepod larvae.

Identity of dominant Coscinodiscus in the Sierra Leone River Estuary—Bainbridge[4] has encountered a centric diatom in abundance in the estuary over the majority of the dry season which he refers it as *Coscinodiscus gigas*. He has also considered another centric diatom, *Actinocyclus octonarius* as the most abundant diatom in the estuary from January to June.

Taylor[5] is of the opinion that the abundant centric diatom in the estuary belongs to *Coscinodiscus gigas — janischi — pavillardi* complex. Findlay[9,10] on the basis of laboratory study of the *Coscinodiscus* refers it as *C. pavillardi,* which is now considered a var. of *C. perforatus*. In the author's opinion, the species which is the subject of controversy belongs to *Coscinodiscus jonesianus* (Grev.) Ostenfeld. The Controversy probably arose due to the possession by one or the other of the fore-going species of marginal spinules and/or of 2 apiculae separated by an angle of 100-120°. *C. jonesianus* is common to abundant over most of the dry season in the present samples. A brief description of the main characters of this species is (see also Hendey[11]) as follows: Cells double convex, valve slightly concave in the middle, diam. 100 μm. Areolae radiate from more or less distinct rosette of large areolae in the centre. Areolae 5-6 in 10 μm near the centre, 8-9 in 10μm at about half radius and 13-15 in 10 μm near the margin, where they appear in obliquely decussating curved lines. Marginal spinulae are 8-10 μm apart, from which narrow hyaline darts run towards the centre. Two large conical apiculae are situated near the margin separated by an angle of 100 to 120°. The following are synonyms for the species: *Eupodiscus jonesianus* Grev., *Coscinodiscus biconicus* van Breemen; *C. jonesianus* var. *commutatus* (Grun.) Hust.; and *Eupodiscus commutatus* Grun.

C. jonesianus appears to be a typical brackish water form. It is found in the Amazon Delta (sal., 13.7°/₀₀)[12] and in the Azov Sea (brackish water)[13].

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Papers Accepted for Publication

Biochemical Composition of the Bivalve Molluscs, Villorita cyprinoides var. Cochinensis (Hanley) & Meretrix casta (Chemnitz)—P T Lakshmanan & P N Krishnan Nambisan, Department of Marine Sciences, University of Cochin, Cochin 682016

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